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CESSNA AIRCRAFT CO.

Pawnee Road Plant
Wichita, Kansas

FC

FINAL SUMMARY REPORT

Contract NONR 856(00)

MODEL 319A : REPORT NO. 1339-7

Flight Test Results on the Use of High Lift Boundary Layer Control Applied to a Modified Liaison Airplane

(Title Unclassified)

REPORT DATE: 31 March 1956

PREPARED BY: Jack W. Fisher
W. Marvin Gertsen
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FOREWORD

This report was prepared by the Research Department, Cessna Aircraft Company, Wichita, Kansas as the Final Report on Office of Naval Research Contract No. NONR 856(00) extending from 1 June 1952 to 31 March 1956. The work reported herein was undertaken with cooperation of the Army Transportation Corps and administered by the Office of Naval Research with Major Willcox and Major Ritter in turn acting as Project Officer.

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ABSTRACT

This report contains the results of flight test to determine the effects of an improved high lift "Arado" boundary layer control system on the performance and stability and control characteristics of a modified Cessna Model L-19A liaison airplane. Tests were conducted by Contractor in the vicinity of Wichita, Kansas between November 1953 and September 1954 under the terms of Contract NONR 856(00). Additional tests were conducted between April and August 1955 under Contract No. AF33(616)-2791. The results of the second series were included in this report since the Contractor believed them pertinent to the general field of research in boundary layer control (BLC).

The use of wing BLC reduced take-off and landing distance over a 50 ft. obstacle by 25% in each case, while maximum angle and rate of climb were essentially the same even though the BLC system was integral (power being supplied by the main engine). The improved performance was primarily due to reduced stalling speed, and more effective lateral control at low speeds. The airplane stalling characteristics with BLC-on were not considered satisfactory with the stall occurring quite abruptly, and with large changes in attitude. The application of wing BLC was stabilizing; however, the forward center of gravity limited by elevator deflection required to land was moved far aft indicating the need for much greater elevator effectiveness.

Throughout the program the test results indicated that further gain in performance was possible with improved and more powerful BLC systems and careful initial design.

INTRODUCTION

Development work on boundary layer control as a high lift device by Germany during World War II resulted in the first practical aircraft installation. Their research was terminated by the war; however, their reports became available and were studied in a number of countries by many agencies. The data was checked and augmented as shown by References 1 and 2. With the sponsorship of the Office of Naval Research (Contract NONR 234(00)) this Contractor undertook in 1951 the construction and flight test of an "Arado" boundary layer control system on a light aircraft, the Cessna Model 170. The results of this program on various BLC pump systems are given in Reference 3.

In general, the ability of the "Arado" BLC system to reduce stalling speed and improve low speed performance such as take-off and landing distance was proven. No attempt was made at that time to design and install a practical system for light aircraft with respect to weight, compactness and cost, but only to collect aerodynamic data and test the various pumping systems. Four systems were investigated including first, electrically operated axial fans, and second, jet pumps with primary flow of air produced by two different liquid monopropellant fuels and by hot gases resulting from combustion of gasoline in compressed air.

During this period a more refined design was readied for installation on a Cessna Model L-19A liaison airplane designated as the Model 319. The original intention was to examine the effect of BLC throughout a range of wing loadings from 15 to 25 lbs/ft.^{2}, and to produce a wing lift coefficient up to 5.0. A wind tunnel model was designed and tested by the University of Wichita and the results are given in Reference 4. In March 1953 this concept was changed by agreement between the Contractor, Office of Naval Research, and Army Transportation Corps to a version which could show a 15 to 20% improvement in performance when compared to a standard L-19A. This reduced the problem of selection of a suitable power source and air pumping system as well as lowering the wing lift coefficient to a value of approximately 3.5. At this lower value the nosing down pitching moment was less and the Contractor believed that difficulties associated with elevator effectiveness and horizontal tail size could be more easily overcome and any unforeseen delays in the program avoided.

The Model 319A incorporated an improved "Arado" BLC system with the power extracted from the engine and transmitted hydraulically to two axial blowers, one located in each wing. The photographs shown by Figures 1 and 2 give views of the airplane in the take-off and landing configuration, and the schematic diagram of Figure 3 illustrates internal arrangement. The aircraft was first flown in November of 1953, and testing continued until September 1954 at which time it was demonstrated as part of the Navy program in the National Air Show at Dayton, Ohio.

Later on, the airplane was tested to determine the effects of wing BLC on stability and control at low speeds. This work was done for the Wright Air Development Center under Contract No. AF33(616)-2791, and is reported on by Reference 5. Resulting from this series of tests a new contract is now being negotiated with WADC for the design, construction and testing of BLC on the tail surfaces with the 319A to serve as the test vehicle.

PERFORMANCE

The total reduction in both take-off and landing distance over a 50 ft. barrier due to the use of BLC was shown to be 25%. In both cases the distance was lowered from 600 ft. to 450 ft. Values of airplane maximum lift coefficient determined from measurement of stalling speed in take-off configuration (full power, δ_F=30° and δ_A=15°) were raised from 2.86 to 3.70 and in the landing configuration (idle or power required for BLC, δ_F=45° and δ_A=30°) from 2.07 to 2.99. The highest value of $C_{L_{max}}$ measured was 6.2 which was obtained with full power, full flaps and aileron droop, and with BLC-on. The corresponding BLC-off value was 3.38. This was achieved even though engine power delivered to the propeller was reduced by approximately 10% due to the BLC requirements. Other items of performance such as maximum rate and angle of climb were substantially unchanged.

Take-off and Landing

Three methods were used to record data for the landing and take-off distance over a 50 ft. obstacle: by use of observers only; by use of a photographic flight path recording camera; by means of a 35 mm Ditto camera. Camera data was supplemented by reading temperature, pressure altitude and wind velocity.

Results of the take-off and landing distances when corrected to standard weight and sea level conditions at first gave varying results. These variations were attributed to changes made to the plane and individual pilot techniques during the test program.

During one take-off test a standard L-19A was flown beside the 319A. Still photographs were taken of the entire flight paths over a 50 ft. obstacle using a Ditto 35mm camera. The 319A was flown at a gross weight of 200 lbs. more than that of the L-19A. This difference exceeded the estimated weight of a production BLC system by 50 lbs. With this weight penalty, ground roll for both take-off and landing was reduced by over 35% and total distance by 25%. Figure 4 is a composite of the series of photographs made during the take-off of the two airplanes, and shows the extent of improvement in distance achieved by the 319A. The sketch of Figure 5 gives the actual distances when corrected to sea level and zero wind conditions.

The improved performance obtained during the latter part of the testing was the result of several factors. Several changes were made to the aircraft, including adjustment of the hydraulic pressure delivered to minimize the power drain from the engine.

Originally stall strips of approximately 3 ft. were attached to the wing leading edge at the root in an attempt to improve stall characteristics. Later these strips were reduced in length to only 6 in. and their chordwise position optimized so as to produce similar stall characteristics to that provided by the larger ones. It was felt that the long strips contributed additional drag thereby limiting total take-off distance. Early in the program measurements of BLC volume air flow indicated values of $C_{Q_B} = 0.0146$ which was far below the design value of 0.018. This was also reflected in performance and in measured stall speeds. Studies of the wing air flow patterns by tuft survey also showed areas of separation on both flaps and drooped ailerons at air speeds greater than the design values of C_L and C_Q. As a result the blowing slot was widened from 0.004c to 0.006c. This reduced the fan back pressure and allowed greater flow quantities to be pumped at the same power input. (refer to Figure 6)

Even with the improvements in $C_{L_{max}}$ produced with the widened blowing slot, total landing distance reduction was not considered satisfactory. An analysis of the data provided by the flight path recording camera showed that the ground roll was very short, but that the approach path was quite shallow resulting in only slight overall reduction when a 50 ft. barrier was considered. This was caused by the effect of BLC increasing the airplane lift to drag ratio. To increase drag and thereby steepen the glide path, the propeller low pitch setting was reduced to 2.5° at 0.75R and at the normal approach speeds and propeller RPM a considerable amount of drag was produced.

The original propeller used governor oil pressure to produce the low pitch setting and counterweights for higher pitch. The counterweights allowed the blade angle to increase at times and not ride on the low pitch stop. This was discovered during measurement of glide sawtooth data which is presented by the next section. A "reverse sense" propeller was installed that depended upon governor oil pressure for the high pitch settings and tended to ride on the low pitch stops without any governor pressure.

These changes eventually resulted in the decreased landing distance mentioned previously. Figure 7 and 8 show the distances which were measured at various stages in the program. It should be pointed out that from the results of these flight tests and from studies made subsequently, the reduction of landing distance was a more difficult problem than that of take-off, and will probably become even more so as speeds and distances ar further reduced.

The importance of pilot technique also became apparent during the test program, again particularly during landing. If approach speeds were allowed to get too high, the airplane had a tendency to float after the flare-out. If approach speeds became too low, proper flareout could not be executed. The range for proper approach speed was only about ± 2 mph which was difficult and dangerous to maintain in gusty air. The best pilot technique used consisted of making the approach and starting the flare at a speed in the upper range and then closing the throttle at the end of the flare. Closing the throttle reduced the BLC power causing the wing lift to diminish. The airplane then settled to the ground without floating and maximum braking was applied resulting in a very short ground roll.

The take-off technique used consisted of raising the tail wheel off the ground as soon as possible to reduce drag and allow the airplane to become airborne as soon as possible. The airplane was then accelerated just above the ground to about 1.1 times the stall speed before being pulled up into transition and climbout.

It was noted during the tests, and analysis of the data, that in a few cases the airplane left the ground at speeds below previously determined stalling speeds. This phenomenon was thought to be caused by maneuvering or the influence of ground proximity. In any case, this was considered an area for possible future investigation.

From wind tunnel data (see Reference 4) and a limited amount of flight testing, best flap and aileron deflections for take-off were determined to be $\delta_F=30°$, $\delta_A=15°$. The flap-aileron deflections for landing were intended to be $\delta_F=60°$ and $\delta_A=45°$, but poor lateral control even with BLC-on prevented the use of these deflections. Instead, $\delta_F=55°$, $\delta_A=30°$ were used for landing. Widening of the blowing slot from 0.004c to 0.006c helped increase the lateral control by increasing the flow quantity. Had a further increase in flow quantity been possible, lateral control probably would have been improved to such an extent that greater flap-aileron deflections could have been utilized.

At the forward center-of-gravity location there was insufficient elevator power with BLC-on to achieve a 3-point landing attitude or to trim the airplane at slow speeds as has already been mentioned. A more detailed discussion of this is given in the section on Stability and Control. This could be overcome by increasing the tail volume coefficient; however, this might prove to be impractical due to the tail size or location necessary. It was felt that a better solution would be to install BLC on the horizontal tail.

Considerable attention was given to barrier landing with high surface wind velocities under gusty conditions. One hard landing was made with flaps up and BLC-off which resulted in damage to the propeller, main landing gear spring, and tail gear spring. To indicate how surface wind would affect overall landing distance Figure 9 was prepared for the landing case with BLC-on. If both approach and landing speeds were increased to give a margin of 10 mph the airplane would still be capable of making a barrier landing within the same distance with surface winds of 8 mph. For an approach normally made at $1.2V_{stall}$ (approximately 54 mph) the additional 10 mph in approach speed would increase the total margin to 19 mph, and the same barrier performance would be retained. In a turbulent atmosphere with vertical gust components the problem becomes more serious since the angle of attack for maximum lift may be exceeded resulting in a true stall rather than simply a lessening of velocity to the point where the wing can no longer sustain airplane weight.

Climb and Glide Performance

Climb and glide performance was investigated to determine how the various changes which were incorporated influenced the lift and drag characteristics of the airplane, and to establish a basis for estimating the effects of BLC and propeller slipstream on the airplane drag polars and lift curves.

In general, BLC increased the effective aspect ratio, lift curve slope, and lift to drag ratio, and reduced $C_{D_{pe}}$ both with and without slipstream effects (take-off and landing configurations). Maximum angle and rate of climb were essentially unchanged except that the speed for maximum angle was reduced by approximately 5 mph. Use of the propeller for drag production to steepen glide path was clearly shown.

The climb performance corrected to standard conditions is presented as follows:

δ_F - δ_A	BLC	V_θ TIAS mph	$V_{R/C}$ TIAS mph	$(R/C)_{max}$ ft/min	Absolute Ceiling	Service Ceiling	θ_{max} (deg)
0 - 0	off	67	79	1510	22,700	21,200	13.6
30 - 15	off	57.5	69	1150	20,000	18,300	12.2
30 - 15	on	52	67.5	1160	19,400	17,700	14.1
45 - 30	off	55	65	990	16,400	13,100	10.7
45 - 30	on	49	63	880	19,200	17,100	9.7

Figure 10 shows the variation of maximum rate of climb with altitude. The data for δ_F=45° and δ_A=30° does not show good agreement since the plots of BLC-on and off are shown crossing at 7000 ft. This data was collected at altitudes between 4000 and 12,000 ft. and may not actually diverge as much as indicated beyond this range. Aerodynamic relationships between C_L, α, and C_D are shown by Figures 11 to 13 and are summarized by the following table:

δ_F - δ_A	BLC	$C_{D_{pe}}$	e	L/D_{max}	$V_{(L/D)max}$ mph	dC_L/d_α	$\alpha_{L=0}$ (deg)
0 - 0	off	.043	1.00	11.75	70.2	0.100	-4.5
30 - 15	off	.080	0.94	8.40	60.1	0.107	-11.3
30 - 15	on	.070	1.20	10.50	60.1	0.150	-9.8
45 - 30	off	.105	0.79	6.60	57.4	0.109	-12.0
45 - 30	on	.110	1.04	7.45	55.3	0.1375	-16.0

All climbs were conducted at full throttle, 2600 RPM, and as rich a fuel mixture as was practicable for smooth engine operation. Data reduction was made by the equivalent altitude method, Reference 7. Values of airplane efficiency factor, e, were assumed and a later check indicated less than 0.5% error in rate of climb.

The major factors affecting the accuracy of the data obtained were: vertical air currents, accuracy of the airplane weight estimation, changes in flap deflection due to air buffeting, and consistency of airspeed, engine RPM and manifold pressure. Data was taken only when it was possible to maintain the airspeed within ± 1/2 mph of the desired velocity. Since all runs were conducted with the propeller control against the full RPM stop and the throttle against full power stop, the RPM and manifold pressure were very consistent. Although the rate of fuel consumption was not constant, plots of total weight change during a flight as a straight line vs. the time of the flight provided sufficient accuracy.

Further details of the climb test program are presented in Reference 8.

Since operation of the BLC system during a landing approach required approximately 20 HP from the engine, 1400 RPM was the lowest practicable engine speed for "BLC-on" glides. In order to compare directly, glides at 1400 RPM, BLC-off were made. During the tests the constant speed propeller pitch-changing mechanism was not functioning properly for the 1400 RPM glides causing inconsistencies in the data obtained. A "reverse sense" propeller was obtained from Hartzell Propeller Company to correct this difficulty. Due to this delay, sufficient time remained to complete tests for only one configuration: δ_F=55°, δ_A=30°. For other configurations, only feathered propeller glides were completed.

Some air turbulence was present during most of the glides. However, the resulting point scatter of measured data was slight.

It is of interest to note that on numerous occasions moderate air turbulence completely invalidated data collected in all phases of the test program. The general level of atmospheric turbulence encountered was normal for Wichita; however, main emphasis was placed on tests at speeds ranging from 35 to 50 mph where small gusts of only several mph had a significant effect on aircraft motion and stick forces. Usual tests at speeds of 100-200 mph were conducted on other aircraft in the same vicinity at the same time without any difficulty.

Aerodynamic data obtained from full feathered propeller glides are given by Figures 14 to 16, and information for isolating the effects of propeller drag (due to low pitch setting of 2.5°) is given by Figures 17 to 19. The following table summarized the glide data:

Configuration						
δ_F - δ_A (deg)	Power	BLC	C_{L_α}	e	$C_{D_{pe}}$	$\alpha_{L=0}$
0 - 0	off-feathered prop	off	.070	.807	.032	- 2.2
0 - 0	full throttle	off	.100	1.00	.043	- 4.5
30 - 15	off-feathered	off	.097	.920	.0634	- 6.0
30 - 15	full throttle	off	.107	.940	.080	-10.2
30 - 15	full throttle	on	.150	1.20	.070	- 9.9
45 - 30	off-feathered	off	.084	.995	.1005	-10.2
45 - 30	full throttle	off	.109	.790	.105	-12.0
45 - 30	full throttle	on	.1375	1.04	.110	-15.9
55 - 30	off-feathered	off	.076	.892	.106	-12.2
55 - 30	req'd for 1400 rpm	off	.072	.646	.163	-12.6
55 - 30	req'd for 1400 rpm	on	.101	.668	.152	-12.8

From comparable glides with the BLC system on and off with flaps deflected 55° and ailerons drooped 30°, the results indicate that the rate of descent was decreased 19.5% (90 mph indicated airspeed), and the effective parasite drag coefficient, $C_{D_{pe}}$, was reduced by 6.7% due to the BLC system. Increases were noted in maximum lift-to-drag ratio (9.4%), airplane efficiency factor, e, (3.3%), and slope of the airplane lift curve (28.7%)

Additional information and data relative to the Glide test program may be seen in Reference 9.

STABILITY AND CONTROL

Of almost equal importance to performance gain was the fact that the airplane was controllable with BLC-on at all speeds down to the stall speed. This was particularly true with respect to lateral control which with BLC-off deteriorated considerably at low speeds. For example, the wing tip helix angle, pb/2V, was increased from 0.05 to 0.09 by use of BLC on the ailerons, comparisons being made at $1.1V_{stall}$ in each case. Longitudinal control was sufficient but, with BLC applied to the wing only, was not subject to the improvement shown in lateral control. This was not the case with forward center-of-gravity (CG) loadings in the landing configurations when elevator effectiveness required for 3-point landings was found to be adequate with BLC-off but not with BLC-on. This was due to a combination of the lower speeds involved and the large nose down pitching moments caused by the wing BLC. Consequently, the improvements in landing performance stated previously were restricted to aft CG loadings. Even though the effect of BLC was stabilizing it would be necessary to increase tail size and tail length or to improve elevator effectiveness. A thorough investigation was not possible within the limitations of the contract; however, some data indicated that horizontal tail area would have to be nearly doubled which indicated that solution of this problem involves improved elevator effectiveness, possibly with the use of BLC. Reference 5 is the final report on Contract No. AF33(616)-2791 and contains all of the flight test information, and corrected data pertinent to the test program. The tests were planned to investigate only those phases in which application of Boundary Layer Control could have an appreciable effect.

LONGITUDINAL

Static Longitudinal Stability

It may be noted from the following table that the effect of BLC was stabilizing for all configurations, as evidenced by the rearward shift of neutral points:

Configuration				Neutral Point (% MAC)	
δ_F - δ_A (deg)	BLC	Power	Trim C_L	Stick-fixed	Stick-free
0 - 0	off	idle	.77	44.5	43.7
0 - 0	off	NRP	.48	39.9	39.4
30 - 15	off	NRP	1.55	36.3	30.3
30 - 15	on	NRP	2.44	55.9	45.2
45 - 30	off	idle	1.01	46.3	42.0
45 - 30	on	*BLC	1.59	52.0	46.0
45 - 30	off	PLF	1.20	35.1	33.3
45 - 30	on	PLF	1.99	44.5	42.8
45 - 30	off	NRP	1.55	33.0	29.1
45 - 30	on	NRP	2.44	38.4	36.5

* BLC power was power required to operate the BLC system only.

Longitudinal Control

Landings and take-offs were made to determine longitudinal control of the 319A. With BLC-on, full 3-point landings could not be made at any CG location, while with BLC-off, landings were marginal at the forward CG (20% MAC). Figure 20 gives the elevator deflection required for 3-point landing and pitch attitude at initial contact. A typical comparison of BLC-on and off landings at forward CG position is given by the time history plot of Figure 21.

These results indicated that the limiting CG position with BLC-off and BLC-on were 21% and 32% MAC respectively. Figure 22 shows these values plotted on a graph of tail volume coefficient ($\bar{V}$) vs. forward C. G. The slope of the lines was estimated from the expression

$$\frac{dx/c}{d\bar{V}} = \eta_t \left[a_t \left(\alpha_t + \tau \delta_e \right) \right] / C_L$$

where α_t is:

$$\alpha_t = \alpha_w - i_w + i_t - \epsilon$$

The downwash angle could only be estimated and the effect of ground influence was considered by halving the theoretical value of ε at infinity. Tail efficiency, η_t, was assumed to be 0.7.

In the take-off tests, the pilot attempted to bring the thrust line to zero attitude ($\theta = +4°$) as soon as possible. Under the circumstances of rough field operation and small amount of time required for a ground run (6 seconds), it was very difficult to maintain this attitude. For this reason, the measured data was inconclusive. However, the data did show that in all cases at a speed of 20 mph (approximately $0.5V_{stall}$ in the take-off configuration) the tail wheel was free, and the pilot had control of the airplane. Examination revealed that at this speed elevator deflection was from 5° to 8° while a total of 21° was available. There appeared to be no difference in longitudinal control effectiveness with BLC-on or off.

Trim Changes

The minimum peak longitudinal control force change of 10 lbs. was exceeded for nearly every configuration change investigated as is shown by the tabulation in the following table:

Trim Changes
CG at 20.25% MAC

In each case column (a) presents the trim conditions and column (b) the configuration change as well as variation of speed. stick forces, etc.

ITEM	1		2		3		4		5	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Configuration	CR		CR		PA		L		TO	
Trim Speed	85		85		73		73		73	
δ_F - δA	0-0		30-15		45-30		45-30		45-30	
BLC	off		off		off		off		off	
Power	PLF		PLF		PLF		IDLE		NRP	
Variable		δ_F=30° δA=15°		BLC on		IDLE		NRP		δ_F=0° δA=0°
Constant	Altitude		Altitude		Speed		Altitude		R/C	
RPM	2615	2590	2600	2600	2595	1250	1210	2600	2600	2650
MP, in. hg.	16.5	16.7	18.7	18.7	19.7	9.5	9.7	25.7	25.2	24.8
F_e, lbs.	0	-2.4	0	3.4	.5	-13.9	-7.3	15.4	0	18.9
α, deg.	9.1	4.9	1.8	-.5	1.6	3.1	3.3	1.8	1.7	4.1
δ_e, deg.	-4.8	-2	-.4	2.9	1.9	-6.1	-2	6.4	1.9	-1.5
δ_s, deg.	-3.4	-3.4	-2.4	-2.5	-3.7	-3.7	-9.3	-9.4	-2.8	-2.6
TIAS, mph	86	72	87	81.5	76	76.5	75	74.5	75	118
h_p, ft.	4700	4530	4600	4605	4565	4050	3280	3225	3930	4310
Gr. Wt., lbs.	2435	2434	2432	2432	2430	2430	2428	2428	2423	2423
OAT, °F.	71	71	72	72	72	70	73	77	76	75

ITEM	6		7		8		9	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Configuration	PA		L		TO		TO	
Trim Speed	58		58		58		58	
δ_F - δ_A	45-30		45-30		45-30		45-30	
BLC	on		on		on		off	
Power	PLF		BLC		NRP		NRP	
Variable		IDLE		NRP		BLC off		δ_F=0° δ_A=0°
Constant	Speed		Altitude		R/C		R/C	
RPM	2590	1240	1500	2600	2590	2610	2610	2645
MP, in. hg.	18.7	15.9	14.9	25.4	25.2	24.7	24.4	24.0
F_e, lbs.	-8.5	-15.7	-15.7	-1.2	-6	13	0	38.2
α, deg.	2.1	5.1	5.1	1.2	1.3	3.1	9.2	4.3
δ_e, deg.	7.4	-7.4	-6.9	9.3	6.4	6.0	.3	.9
δ_s, deg.	-9.4	-9.3	-9.3	-9.3	-9.4	-9.4	-5.1	-5.1
TIAS, mph	57.5	57.5	57	57	57.5	71	57.5	115.5
h_p, ft.	4860	4435	3715	3725	4025	4400	4815	5210
Gr. Wt., lbs.	2420	2420	2417	2417	2415	2415	2414	2414
OAT, °F.	71	70	70	74	75	73	72	70

Measurements were taken prior to and approximately 5 seconds after the pilot initiated action causing the change. It should be noted that in some cases it was impossible to trim the airplane to desired speeds at forward C. G., and for this reason stick force appeared in the trim column. The greatest stick force variation occurred with the retraction of flaps at 1.5 V_{STO}. The action of turning BLC-on with 30° of flaps in CR configuration produced acceptable stick force changes, but with 45° of flaps and in the TO configuration a total variation in stick force of 19 lbs. occurred. The difference was partially due to power and flap deflections, but was probably affected more by speed differences. The trim speed for CR configuration was 85 mph and only 58 mph for the TO configuration. At the lower speed the strength of the BLC system was considerably greater due to greater values of C_Q.

In changing from the Power Approach (PA) configuration to idle RPM the effect of BLC was to reduce stick force variation to an acceptable value (-7.5 lbs.); however, due to the fact that the airplane could not be trimmed with BLC-on the peak force exceeded the allowable of 10 lbs. The same reduction was true with the application of full power to Landing (L) configuration except that the total variation and peak forces exceeded specification values both with BLC-on and off.

In Take-off (TO) configuration if the sequence of turning off BLC and raising flaps was considered to be one operation without a trim change the stick force variation would have been much greater

Longitudinal Trim

The trim speed range of the airplane at forward CG (20% MAC) was quite poor particularly in the glide configuration with the minimum trimable speed being approximately 83 mph either with or without BLC. Only limited data could be obtained (see Figure 23) due to the fact that structural flaps down limit speed was 85 mph, and due to the fact severe flap buffet occurred with BLC-on at speeds above 65 mph. With CG at 30% MAC (Figure 24) the minimum trim speeds were 60.5 and 64 mph for BLC-on and off respectively. Maximum performance landings were made at a BLC-on approach speed of 52 mph ($1.15V_{S_L}$) which required continual pull force even at the aft CG. BLC-off approaches were made between 60 and 65 mph which was closer to trim conditions.

Figure 24 shows that with full power (NRP) and flaps down the stick-free neutral point for BLC-off was being closely approached with the CG at 30% MAC, since the airplane could be flown at any speed between 45 and 50 mph with zero stick force. The application of BLC with same configuration produced a stabilizing effect. This was also shown by measurements of static longitudinal stability.

Maneuvering Stick Forces

The Model 319A in BLC-off configuration exhibited normal maneuvering stability characteristics, although stick force gradients were in excess of desired values. With BLC-on, $\delta_F=45°$, $\delta_A=30°$ the airplane showed a positive stick force gradient for the interval from 1.0 to 1.2 g's, beyond this point the gradient assumed the normal negative direction (see Figure 25). Examination of this situation led to the conclusion that with the large value of stabilizer incidence used ($i_t = -9°$), a partial tail stall was possible, which could have over-balanced the elevator and resulted in positive value of C_{h_δ}. Additional flights made with $i_t = -7°$, and $-5°$ corrected the situation at $i_t = -5°$, thus supporting the conclusion. (see Figure 26) It was felt that relocation of the tail could eliminate the problem.

LATERAL

Sideslip Characteristics

In tests of wings level steady sideslips with flaps down and ailerons drooped, power-on, the use of BLC corrected a rudder lock tendency found in the same configuration with BLC-off as shown by Figure 27. This was apparently due to reduction in turbulence at the vertical tail as a result of suction over the flap section. No rudder reversal was found in the power-on clean configuration.

Aileron control characteristics in the sideslip were erratic. Static stick-fixed lateral stability with BLC-off was positive and of acceptable magnitude, but was nearly neutral with BLC-on. Stick-free lateral stability was essentially neutral in clean power-on configuration at the low speeds tested. At low speed the BLC-on configurations exhibited a slight negative dihedral effect.

Lateral Control

Rudder fixed aileron rolls demonstrated a marked improvement in lateral control due to BLC. This improvement was particularly evident for cases with 30° aileron droop, where pb/2V was increased due to BLC by 76% and 103% in rolls to the right and left, respectively. No measurements were made with BLC-on and no droop, but the improvement with 30° droop BLC-on, compared to BLC-off no droop, was 33% and 29% for right and left rolls. Figures 28 and 29 contain summary curves showing this comparison.

As a result of the low test speeds, sideslip angle increased rapidly in the rolls. The changes were in the direction of the roll, and in many cases the maneuver resulted in approximately a coordinated turn. Some adverse yaw at the beginning of BLC-off rolls was experienced, but this became favorable as the roll progressed.

STALLING CHARACTERISTICS

Stalling characteristics of the airplane both BLC-on and off were not considered satisfactory. Stalls usually began with an abrupt roll to the right with little or no advance warning. Greater attitude changes occurred with BLC-on. Opposite rudder and full forward stick were used for recovery, with a considerable loss of altitude.

It was felt that with adequate stall warning, the stalling characteristics would have been marginally acceptable except for BLC-on, $\delta_F=45^\circ$ and $\delta_A=30^\circ$. In this case roll of over 70° with pitch angles of nearly 50° below level was observed (refer to Figures 30 and 31).

The table below gives values of $C_{L_{max}}$ obtained from averages of at least two stalls. Data is given for both slot widths tested and the improvement brought about by the wider slot, previously mentioned, is easily seen.

$C_{L_{max}}$

BLC-off		s = 0.004c	BLC-on	
Power off	Power on	δ_F - δ_A	Power off	Power on
1.36	2.06	0 - 0	---	---
1.67	2.66	30 - 15	2.32	3.65
1.77	2.72	40 - 20	2.44	3.91
1.96	3.28	55 - 30	2.50	4.39

BLC-off		s = 0.006c	BLC-on	
Power off	Power on	δ_F - δ_A	Power off	Power on
1.36	2.06	0 - 0	---	---
1.84	2.86	30 - 15	2.39	3.70
2.07	3.38	45 - 30	2.99	4.67
2.03	3.25	55 - 30	2.88	6.2

The only configurations tested which were directly comparable to the wind tunnel results (Reference 4) are shown on the graph of Figure 32. Since the wind tunnel model was a semispan wing only, it was felt that the correlation was quite good when tail trim loads and fuselage effects were considered.

Measured values of air flow quantity coefficient, C_Q, are given in Figure 33, and the variation of air flow with airplane speed in Figure 34. The variation of Q with velocity was consistent with previous results, except for flaps and ailerons fully deflected where at speeds greater than 40 mph the quantity increased. From tuft observations this was also the approximate speed at which the flow over the suction flap separated. Apparently as separation occurred the demand on fan pressure output decreased allowing a greater quantity to be pumped but not enough to unstall the flap. This did not occur for $\delta_F=30°$ and $\delta_A=15°$ since the suction flap was more effective at all speeds tested.

Simulated BLC Failure

During the stall phase of the test program, several attempts were made to simulate BLC failure by turning off the system while flying at a pre-established speed. In all cases except those at very close to the BLC-on stall speed, very little occurred except a slight pitch up, an increase in speed of about 5 mph in 4 seconds, and some reduction in rate of climb or increase in rate of descent. When speed was reduced to a value very close to the BLC-on stall speed, say 36 mph, and BLC turned off, a more definite stall occurred, with the characteristic roll to the right, beginning about 2 seconds after the BLC system was cut off. Rate of climb was definitely reduced and speed increased until the full stall developed. Maximum performance take-offs and landings were made with the 319A at speeds of 42 and 52 mph respectively, which correspond to the simulated BLC failure conditions. This led to the conclusion that, for this general type of airplane, the consequences of a BLC system failure at speeds near the BLC-off stall speed would not be serious.

Symmetrical failure only was investigated. However, it can reasonably be expected that failure of a single pumping unit would result in a large rolling motion and pitch change which could have serious consequences near the ground. This possibility could be eliminated by a single unit for both wings, or by use of device which would cross feed power or air through a common manifold.

DESIGN

Sources of Power for BLC

Numerous sources of power and means of power transmission were investigated during the course of the program: the prime power plant of the airplane with mechanical, electric, and hydraulic transmissions; and independent or auxiliary units utilizing liquid and solid propellants along with turbine drives at the axial blowers. Also considered was the use of a small auxiliary two-cycle engine. A search was made for a suitable turbo-fan (or ducted fan) which would fit inside of the wing, but none was found that had the desired pumping characteristics. Many considerations were taken into account such as complexity, state of development and availability, weight, cost, ease of maintenance, etc. The main engine was selected as the BLC power source on the 319A. Power was transmitted by a hydraulic pump and motors. Selection of the system was based on 1) ease of modification of the engine accessory drive and 2) availability of high efficiency hydraulic components. However, power available for thrust during take-off was reduced about 10%.

Another system was bench tested, but not installed on the airplane. Components of this system were a small air compressor, high pressure storage spheres, a hot gas generator, a turbine and axial blowers. The energy available from the compressed air was augmented by injecting fuel and burning the mixture. It appeared that the installed weight of this system would be relatively low. Operational procedure would include storing high pressure air at a moderate rate during warm up or cruise and using this air at a rapid rate during take-off or landing. This design offers further performance improvement since it drains no engine power during take-off. During the initial bench tests on this compressed air-gasoline system the design power output of the turbine was not achieved. This was due to turbine efficiencies being considerably less than originally estimated by the manufacturer; however, such a system still appeared feasible. The systems involving liquid or solid propellants were eliminated for installation on the 319A since their development cost would have equaled or even exceeded the funds allotted for the entire program.

Model 319A Design Description

After an exhaustive survey the pumping system was established as two axial flow fans (one in each wing) designed by Joy Manufacturing Company. The fans were designed to produce 6.9 air horsepower at 12,000 RPM (see Figure 6) by gearing to motors of 8.5 HP operating at 6000 RPM.

The system selected to drive the fans was that of an engine driven variable displacement hydraulic pump actuating two hydraulic motors geared to the fans. The system as shown in Figure 35 consisted largely of hydraulic equipment manufactured by Vickers, Inc., Detroit, Michigan. The characteristics of the hydraulic pump were such that its RPM could be varied from 1800 to 3900 while maintaining the motors at 6000 RPM and the line pressure at 3000 psi. At this RPM and pressure the motors were delivering to the fans the rated output of 8.5 HP (see Figure 36). This was determined by the required low power of the airplane during landings with the BLC operating. The pump was mounted on the rear of the engine on a special pad with a 1.5 to 1 step-up gearing between the engine crankshaft and the pump.

The power plant selected for the Model 319A was a modified Continental Model 0-470-A rated at 228 BHP at 2600 RPM (see Figure 37). The hydraulic system operating at rated conditions required 20 HP from the engine and 3 HP with fans unoperating. The propeller was a Hartzell constant speed with a special low pitch setting of 2-1/2°. Variation of propeller thrust, efficiency, and blade angle with speed is given by Figure 38.

The flaps, aileron droop and aileron trim were electrically operated allowing optimum settings to be determined during flight testing. A wide angle total head tube and a boom mounted swivel static head were connected to an extra sensitive airspeed indicator to give accurate low speed readings.

The empty weight of the Model 319A was 1891 lbs. which included all BLC equipment. A comparison of various components of the production L-19A with the Model 319A follows:

Item	L-19A	319A	Difference
BLC hydraulic system and fans	---	154	+ 154
Wings - complete with ducts	239	389	+ 150
Propeller, Governor and Control	45	69	+ 24
Engine, inc. accessories less hydraulic pump	434	471	+ 37
Control System (weight difference)	14	28	+ 14
Empennage	76	80	+ 4

The increase in wing weight was due largely to the addition of airflow ducts. The ducting was installed in such a manner that it could be removed and modified. It did not form a structural part of the wing and, therefore, contributed a considerable weight increment. The increase in propeller weight was due to the requirement for a constant speed propeller. The experimental nature of the airplane accounted for the remainder of the weight growth.

A full scale mock-up of a "vortex-flow" type suction duct was built and tested by the University of Wichita (Reference 10). This type of duct, as illustrated by Figure 39, required excessive pumping power, and therefore, the "vortex flow" concept was abandoned.

A full scale mock-up of a "constant loss" suction duct was then built and tested. The theory of this design, used on the Model 319A, was developed by K. Razak, University of Wichita, as presented in Reference 11. The design was based on the premise that loss in total pressure was a function of duct dynamic pressure. Thus, with constant spanwise flow and evenly distributed entrance flow along the span, losses were uniform spanwise and were predictable. With the results of the mock-up tests, the suction duct was designed with an 8 in. diameter, and constant 2 in. entrance slot width and varying throat width (Figure 40) as dictated by dynamic pressure in the duct.

The blowing duct design was based on the premise that a constant pressure differential between the duct and slot would produce uniform spanwise flow distribution. Therefore, with a given pump output, the blowing duct was designed so that the static pressure along the duct axis was constant. This required that the duct diameter be continuously tapered from an 8 in. diameter at the fan as shown in Figure 41. Losses in flow total pressure were determined from Reference 12.

The inboard end of the blowing duct at the fan required a diffuser in order to reduce the losses of an abrupt expansion at the fan exit. The diffuser of an annular type was designed by the method given in Reference 12.

The construction material of the suction duct, blowing duct and diffuser was fiberglass. This one-piece design resulted in a smooth interior, eliminated the possibility of leakage and, therefore, reduced pumping power required.

The quantity flow, Q, required to achieve a design $C_{L_{max}}$ of 3.5 was calculated by:

$$Q = C_{Q_B} S_B V = 29.05\, S_B\, C_{Q_B} (W/S\, C_{L_{max}})^{1/2}$$

where C_{Q_B} was based on wing area, S_B, affected by the blowing slot, and related to C_{Q_S} by $C_{Q_S}/C_{Q_B} = 1.34$. C_{Q_B} was taken from Figure 32. Air horsepower required to pump this quantity flow, Q, was calculated by:

$$HPa = \triangle P_Q / 550$$

where

$$\triangle P = q(C_{Q_B}{}^2\, \eta_B + C_{Q_S}{}^2\, \eta_S + C_{P_{st}})$$

The values of η_B and η_S were determined as shown in Reference 13 to be 4.65×10^4 and 0.47×10^4 respectively. The value contributed by diffusion in Reference 13 was adjusted downward to account for improved diffuser design. The remaining design constants of W/S = 13.5 lb/ft^2 and S_B = 85 ft^2 being known allowed the quantity flow to be calculated.

Compressed Air-Gasoline System

The pumping system consisted of a ducted axial-flow fan gear driven by a small turbine. The turbine derived power from combustion gases of a compressed air and gasoline generator. Compressed air was supplied by a portable air compressor and stored at 3000 psi in two 1300 cu. in. aircraft type steel spheres. With the 250 psi gas generator chamber pressure at 1500°F. the exhaust gases were lead through stainless steel tubing to the turbine, simulating an actual aircraft installation as shown in Figure 42. A line diagram of the bench test setup is given by Figure 43. The turbine was rated at 24,000 RPM and geared to drive the fan at 12,000 RPM.

The 8 in. diameter ducting aft of the fan exit was equipped with instrumentation for measuring flow quantity and a choke plate to vary pressure head.

The system was operated by a single switch located on a control box containing an RPM indicator and an automatic overspeed control for the turbine.

A summary of the bench test weight-breakdown is shown in the following chart on the basis of an actual airplane installation.

Item	Quantity	Total Weight
Air sphere	2	32.0*
Turbine	2	20. **
Fan	2	34.4
Gas generator	1	2.7
Fuel pump and motor	1	3.0
Solenoid valve	2	2.4
Regulator, air	1	1.5
Lines and fittings	--	9.0
Air	--	13.4
Gasoline	--	.3
Miscellaneous	--	1.0
Pressure relief valve	2	.6
Check valve	2	.8
Compressor	1	13.3
Ignition unit	1	5.1
RPM indicator and overspeed control	1	4.1
Fuel strainer	1	.8
Chemical dryer	1	1.2
Pneumatic dryer	1	3.1
Total Weight		148.7

* 870 cu. in. capacity fiberglass plastic spheres.

** Assuming that a specific turbine design would result in a weight savings as compared to the off-the-shelf item used in the bench test.

During the testing of the above system, it developed that the turbine was unable to produce sufficient power to drive the fan at speeds greater than 5000 RPM. Measurements of fan output, volume flow and pressure rise, were made but were of no significance because the fan was operating at only 42% of rated speed. Since power is a function of RPM^3 it was estimated that fan input was 0.6 horsepower at 5000 RPM instead of 8.5 required at rated RPM. Reaction Motors, Inc.

engineering, who supplied the turbine has estimated that in order to produce the rated fan RPM of 12,000, the mass flow of gases to the turbine would have to be doubled.

Summary Comparison of 309 and 319A BLC Systems

In research work spanning from 1951 to 1956 and performed under Contracts NONR 234(00) and NONR 856(00), the following types of boundary layer control systems have been designed and tested:

	Type	Power	Test Source
1.	Jet pump	Gas turbine	Model 309
2.	Axial-flow fans	D.C. generator and electric motors	Model 309A
3.	Axial-flow fans	D.C. storage batteries and electric motors	Model 309A
4.	Jet pump	Ethylene Oxide (C_2H_4O)	Model 309B
5.	Jet pump	Hydrogen Peroxide (H_2O_2)	Model 309C
6.	Axial-flow fans	Engine driven hydraulic pump and motors	Model 319A
7.	Axial-flow fans	Air-gas turbine	Bench Test

The chart on page 28 summarizes the general characteristics of each of the systems. More detailed data can be found in References 14 to 20. The systems involving gas generators and/or turbines (309, 309B, 309C and bench test) required approximately the same operating procedures. Essentially, each procedure consisted of operating simple toggle switches and checking instruments. The monopropellant systems (309B and C) were limited in continuous operating time due to the fuel supply available. Increased operating time could be attained with a greater weight penalty. The bench test operating time of the air gas turbine was limited due to compressed air storage capacity as was the battery powered 309A due to the large power drain on the batteries. Increased continuous operating time, in each case, again could have been attained with a greater weight penalty. The 319A system, as previously described, was unlimited in this respect.

Refueling operations were not required by the systems installed in the 309, 309A, 319A and by the bench tested system except for fuel from the airplane tanks. The monopropellant systems, however, both required a special service vehicle to dispense the fuel and compressed gases necessary for starting, purging and operation. Personnel involved in refueling and operation of the aircraft were required to be thoroughly familiar with proper techniques to handle ethylene oxide and hydrogen peroxide.

Maintenance required by the various systems was ordinarily no more than that required by the basic airplane power plant with the exception of the monopropellant types. In addition, both monopropellant systems required, besides the fuel, other chemicals and compressed gases which were not readily available under normal service conditions.

The temperature (200° F.) of the hot gases of combustion (or decomposition)being ejected over control surfaces on the jet pump and bench test systems caused structural problems of thermal expansion. In addition, the heat generated in the vicinity of the gas generators and exhaust tubing was found to be high even though these items were insulated with stainless steel foil.

The weights listed in the table are entirely for experimental installations. Each of the installation weights doubtless could be improved considerably through careful design for a production airplane. Additional weight savings could be obtained due to the rapid development of chemical, electrical and hydraulic components of each system.

The jet pump installations proved to be very inefficient (on the order of 3%) from power input and output considerations. The electrical system of axial flow fans on the 309A demonstrated considerable improvement with a system efficiency of 21%, but also showed an increased weight penalty. The 319A hydraulic system and axial flow fans, as previously discussed, was the most efficient and practical of all previous types tested by a considerable margin with a system efficiency of approximately 55%.

COMPARISON OF BLC SYSTEMS

Item	309 Gas Turbine	309A Generator Driven Fans	309A Battery Driven Fans	309B Ethylene Oxide	309C Hydrogen Peroxide	319A Hydraulic Powered Fans	Bench Test Air Gas Turbine
Weight	234.0 lbs.	231.2 lbs.	548.2 lbs.	315.0 lbs.	364.0 lbs.	154 lbs.	149 lbs.
Continuous Operating	Unlimited	Unlimited	30 seconds	2 minutes 40 seconds	4 minutes 30 seconds	Unlimited	2 minutes
Start Procedure	1. Gate valve "Closed" 2. Turbine Fuel "On" 3. Turbine Starting "Start" 4. Check Instruments 5. Gate valve "Open" 6. Allow 5 sec. to clear burner 7. Burner "On"	1. Set Engine RPM at 1300 2. Turn Generator "On" 3. Turn individual fans "On"	1. Fans "On" 2. Batteries "On"	1. Power "On" 2. Actuate Start Switch 3. Check Gages	1. Check Gages 2. Actuate Arm Switch 3 Actuate Start Switch 4. Check Generator Press	1. Engine RPM "idle" 2. Needle valve "closed" 3. Check Gages	1. Switch "on" 2. Check Gages
Stop Procedure	1. Burner - "Off" 2. Allow 30 seconds to clear burner 3. Turbine Stopping "Stop" 4. Turbine Fuel "Off"	1. Fans "Off" 2. Generator "Off" 3. Idle Engine	1. Batteries "Off" 2. Fans "Off"	1. Actuate Stop Switch 2. Power "Off"	1. Deactivate Start Switch 2. Deactivate Arm Switch	1. Needle valve "open"	1. Switch "off"
Refueling	Continuous Fuel Supply From Airplane Wing Tank	NONE	NONE	Time - 15 minutes Equipment - Service Vehicle Men - one	Time - 30 minutes Equipment - Service vehicle Men - Two	NONE	Continuous Fuel Supply From Airplane Wing Tank
Maintenance	1. 25-hour general system inspection 2. 50 starts - oil and filter change 3. 100-hour - spark plug and fuel filter change 4. 400 starts - inspection and overhaul	25-hour Inspection of Complete System	Recharge Batteries after 10 Cycles of Operation 25-hour Inspection of Complete System	Check Storage Battery After 2 minutes After 12 minutes - inspect fuel injector and mixing manifold - pressure check fittings After 30 minutes - check remaining system	Change Catalyst after 12 min. of operation Drain and Flush after periods of inactivity	25-hour general inspection	25-hour general system inspection

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APPENDIX A

List of Symbols

C_D	drag coefficient, D/qS
$C_{D_{pe}}$	effective parasite drag coefficient
C_L	lift coefficient, W/qS
C_{Q_B}	blowing flow coefficient, $Q/S_B V$
C_{Q_S}	suction flow coefficient, $Q/S_B V$
$\overline{V}$	tail volume coefficient, $S_t\, l_t/S\,c$
a_t	slope of the tail lift curve, per deg.
b	wing span, ft.
c	wing chord, ft.
D	airplane drag, lbs.
e	airplane efficiency factor
F_e	elevator stick force, lbs.
F_r	rudder force, lbs.
g	normal acceleration, ft/sec/sec.
h_p	pressure altitude, ft.
i_t	horizontal stabilizer incidence, deg.
i_w	wing incidence, deg.
l_t	tail arm length, ft.
L	airplane lift, lbs.
p	rate of roll, rad/sec.
ΔP	total pressure rise, lbs/sq. ft.
q	free stream dynamic pressure, lbs/sq. ft.

q_t	dynamic pressure at the tail, lbs/sq.ft.
Q	volume air flow, cu.ft./sec.
S	wing area, sq.ft.
S_B	wing area affected by blowing, sq.ft.
S_S	wing area affected by suction, sq.ft.
S_t	horizontal tail area, sq.ft.
V	velocity, ft./sec.
V_θ	velocity for maximum angle of climb
$V_{R/C}$	velocity for maximum rate of climb
V_{S_L}	stalling speed, landing configuration
$V_{S_{TO}}$	stalling speed, take-off configuration
W	airplane weight, lbs.
x	airfoil chordwise ordinate, ft.
α	angle of attack, deg.
$\alpha_{L=0}$	angle of attack for zero lift, deg.
α_t	angle of attack, horizontal tail, deg.
α_w	angle of attack, wing, deg.
β	angle of sideslip, deg.
δ_a	total aileron deflection, deg.
δ_A	aileron droop, deg.
δ_e	elevator deflection, deg.
δ_F	flap deflection, deg.
δ_r	rudder deflection, deg.

δ_s	horizontal stabilizer incidence, deg.
ϵ	angle of downwash, deg.
η_B	blowing pressure loss coefficient
η_S	suction pressure loss coefficient
Θ	angle of climb or pitch attitude, deg.
$\tilde{\tau}$	elevator effectiveness, $d\alpha_t/d\,\delta_e$
ϕ	angle of roll, deg.

Abbreviations

BLC	boundary layer control or power required to operate only BLC
CBHP	corrected brake horsepower
CG	center of gravity
MAC	mean aerodynamic chord
OAT	outside air temperature
NRP	normal rated power
PLF	power required for level flight
R/C	rate of climb
TIAS	true indicated air speed

Airplane Configurations

BLC	Landing, BLC-on: Flaps down and engine power required to operate the BLC system.
CR	Cruise: Flaps up, BLC-off, engine power required for level flight at trim speed
G	Glide: Flaps up and power off.
L	Landing, BLC-off: Flaps down and power off.
PA	Power Approach: Flaps down and power required for level flight at normal approach speed.
TO	Take-off: Flaps in take-off position and take-off power.

APPENDIX B

DESCRIPTION OF AIRPLANE

The Cessna Model 319A was a single-engine high-wing liaison-type airplane of all-metal semi-monocoque construction. It utilized the fuselage of standard Cessna Model L-19A, and the tail surfaces of a Cessna Model 180, and contained, in a specially designed wing, an improved "Arado" type Boundary Layer Control System.

The following table presents a detailed description of the airplane:

Airplane	Cessna Model 319A
Overall length, Ft.	25.33
Height, Ft.	7.50
Engine	Continental 0-470-A-104-27X
Rating	
Take-off Power	225 HP at 2600 RPM
Normal Power	225 HP at 2600 RPM
Normal Power (BLC-on)	205 HP at 2600 RPM
Propeller	Hartzell Constant-Speed HC82xF-6
Diameter, Ft.	7.33
No. of Blades	2
Wing	
Area (including fuselage), $Ft.^2$	174.00
Suction Area, $Ft.^2$/wing panel	31.74
Blowing Area, $Ft.^2$/wing panel	42.53
Span, Ft.	36.00
Root Chord, Ft.	5.33
Tip Chord, Ft.	3.71
Taper Ratio	.695
Aspect Ratio	7.45
Root Incidence	+1°30'
Tip Incidence	+1°30'
Washout at Tip	0°
Dihedral	2°30'
Sweep Back of Leading Edge from Sta. 00	2°45'
Mean Aerodynamic Chord, Ft.	4.95
Leading Edge MAC Location, Ft., Aft Firewall	1.80
Airfoil Section (Root NACA 23018 - Tip NACA 23012)	

Wing Flaps (Suction)	
Type	**
Total Area, $Ft.^2$	15.86
Span (each), Ft.	5.95
Chord, Ft.	1.33
Slot Width, in.	2.00
Wing Flaps (Blowing)	
Type	Slotted
Total Area, $Ft.^2$	8.58
Span (each), Ft.	3.36
Chord, Ft.	1.28
Slot Width	0.006c
Ailerons	
Total Area, $Ft.^2$	13.00
Span (each), Ft.	6.05
Chord, Ft.	1.08
Stabilizer	
Area (including section through fuselage), $Ft.^2$	23.32
Angle of Incidence, Deg.	+1.0 to -8.0°
Airfoil Section (Root NACA 0009 - Tip NACA 0006)	
Elevator	
Area, $Ft.^2$	16.33
Span, Ft.	11.15
Maximum Chord Behind Hinge Line, Ft.	2.04
Balance Area, $Ft.^2$	1.18
Vertical Tail	
Total Area, $Ft.^2$ (incl. dorsal)	14.84
Fin Area, $Ft.^2$ (incl. dorsal)	11.35
Rudder Area, $Ft.^2$	7.75
Vertical Span, Ft.	5.083
Maximum Chord Behind Hinge Line, Ft.	1.97

Control Surface Deflections

	Up	Down
Elevator, Deg.	25	21
Rudder, Deg.	24R	24L
Ailerons, Deg.	20R	17R
	22L	17L
Wing Flap, Deg. (Static-suction)	0	55
Wing Flap, Deg. (Static-blowing)	0	48
Aileron Droop, Deg.	0	45
Aileron Travel in Droop Attitude, Deg.	13	13

** Reference 4

Weight and Balance	
Gross Weight, Lbs. (structural)	2450
Empty Weight, Lbs.	1840
Most forward c.g. location %MAC (structural) . . .	19
Most rearward c.g. location %MAC (structural). . .	32
Miscellaneous	
Fuel Capacity, Gals.	50
Limit Maneuvering Load Factor	4.4

Figure 1

Cessna Model 319A - Take-off Configuration

Figure 2

Cessna Model 319A - Landing Configuration

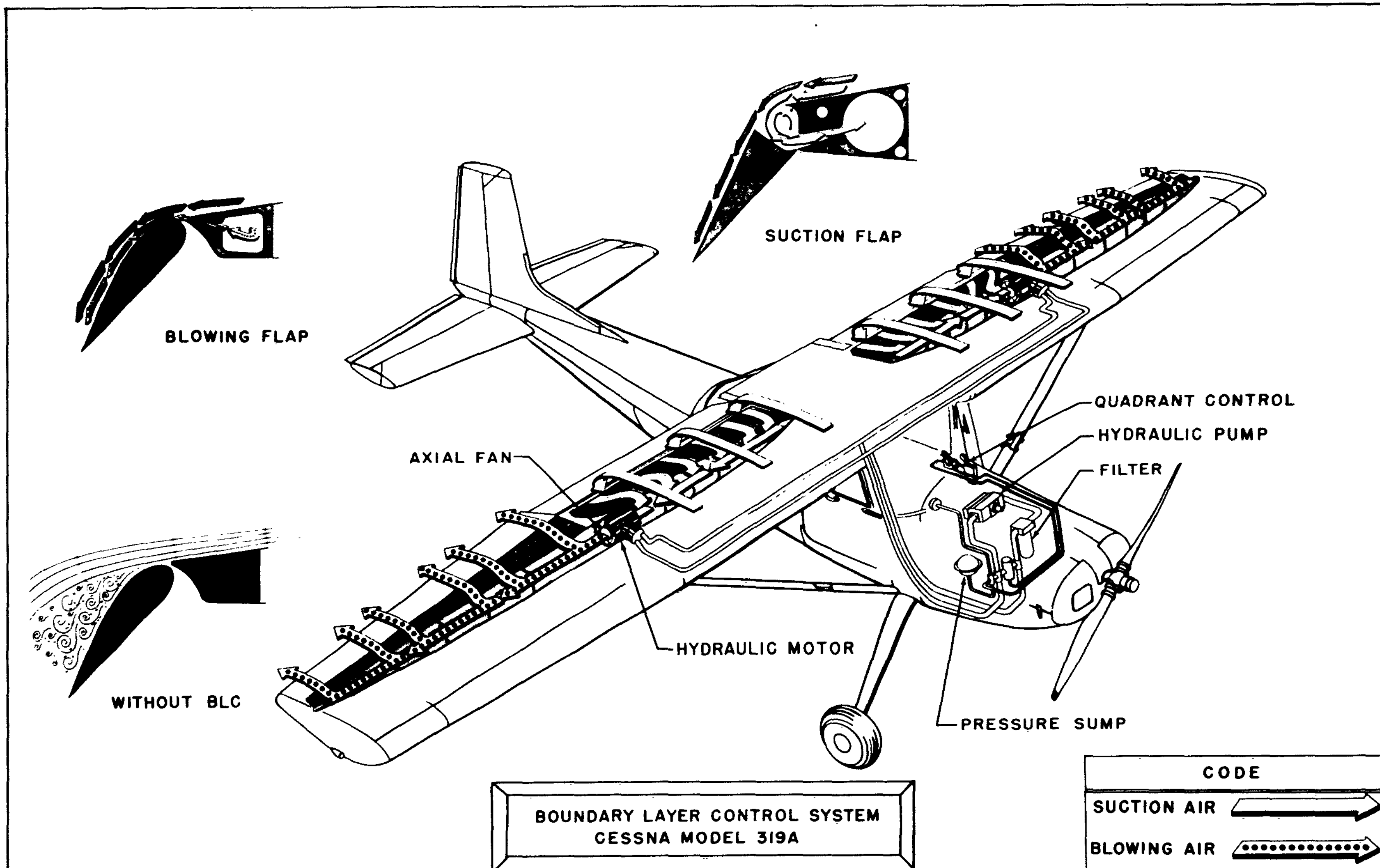

SUCTION FLAP
BLOWING FLAP
WITHOUT BLC
AXIAL FAN
HYDRAULIC MOTOR
QUADRANT CONTROL
HYDRAULIC PUMP
FILTER
PRESSURE SUMP
BOUNDARY LAYER CONTROL SYSTEM
CESSNA MODEL 319A
CODE
SUCTION AIR
BLOWING AIR

Figure 3

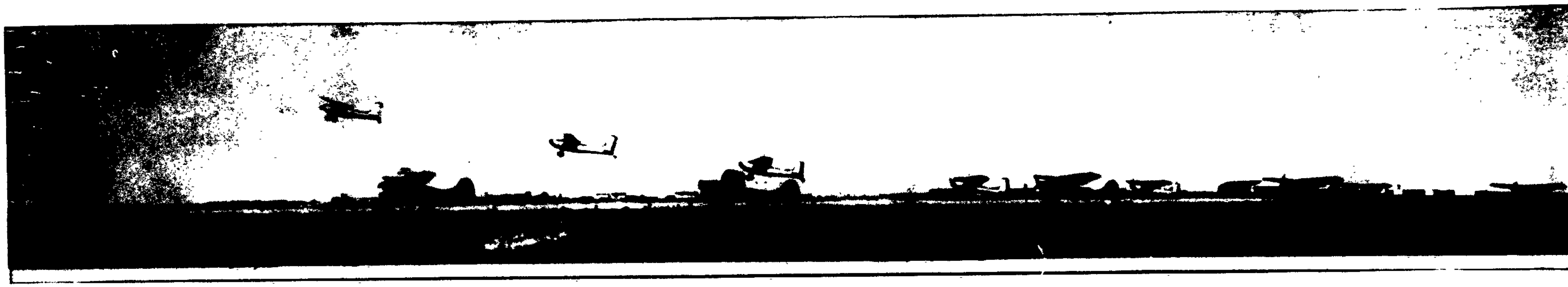


Figure 4

The above figure is a photograph of a typical take-off of Model 319A along with a standard L-19A. This photograph is a composite of a sequence of photographs, made with a Ditto 35 mm camera, taken from the beginning and throughout the take-off run. The two aircraft were side by side at the beginning of the run, and as the run progressed, the L-19A gained velocity faster, but required a considerably greater length of runway in order to break ground and to climb to 50 ft. In this sequence the L-19A weighed 2100 lbs., and the 319A weighed 2300 lbs.

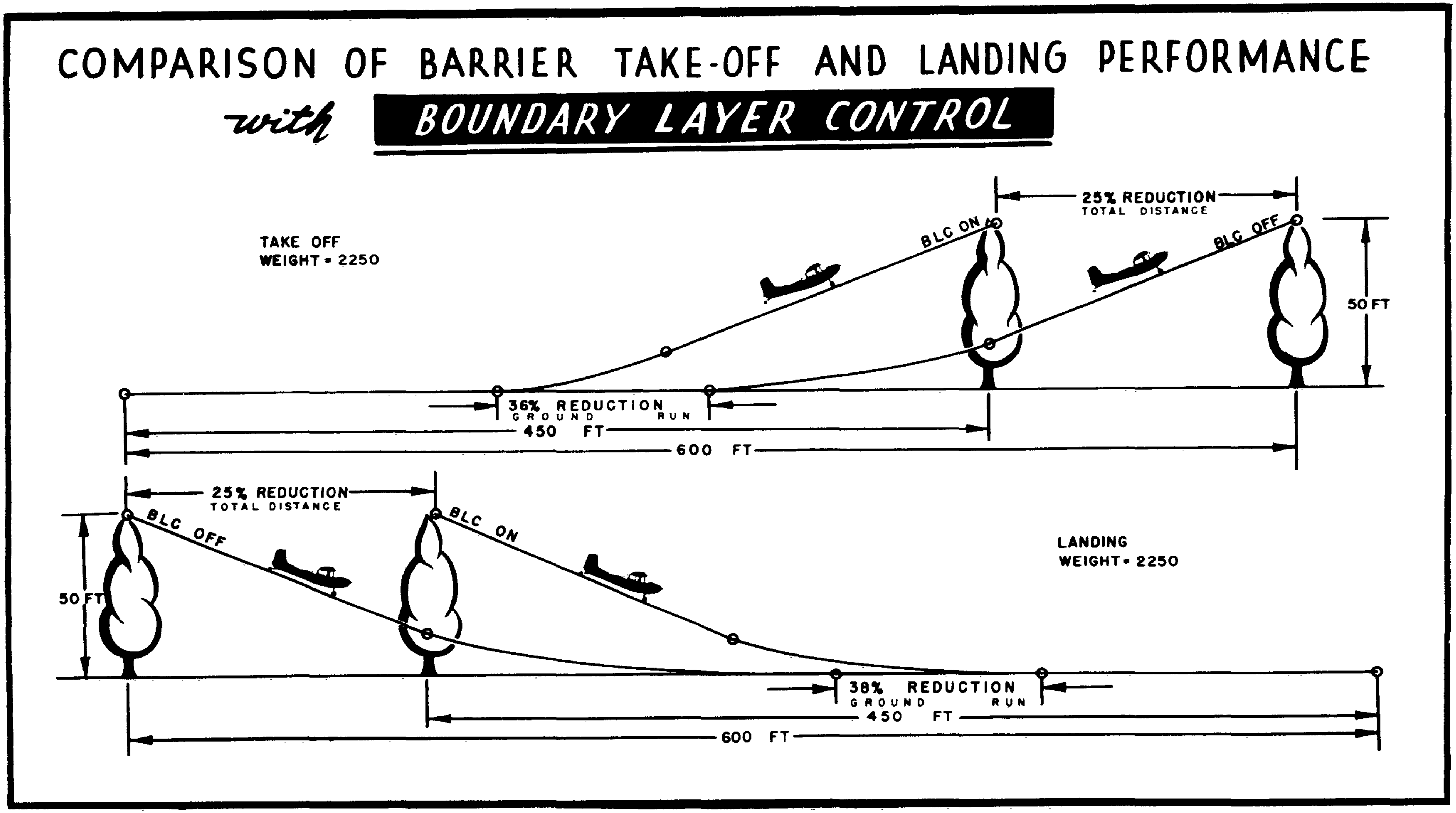

COMPARISON OF BARRIER TAKE-OFF AND LANDING PERFORMANCE
with BOUNDARY LAYER CONTROL
TAKE OFF
WEIGHT = 2250
25% REDUCTION
TOTAL DISTANCE
BLC ON
BLC OFF
50 FT
36% REDUCTION
GROUND RUN
450 FT
600 FT
25% REDUCTION
TOTAL DISTANCE
BLC OFF
BLC ON
LANDING
WEIGHT = 2250
50 FT
38% REDUCTION
GROUND RUN
450 FT
600 FT

Figure 5

MODEL 319A
FAN PERFORMANCE

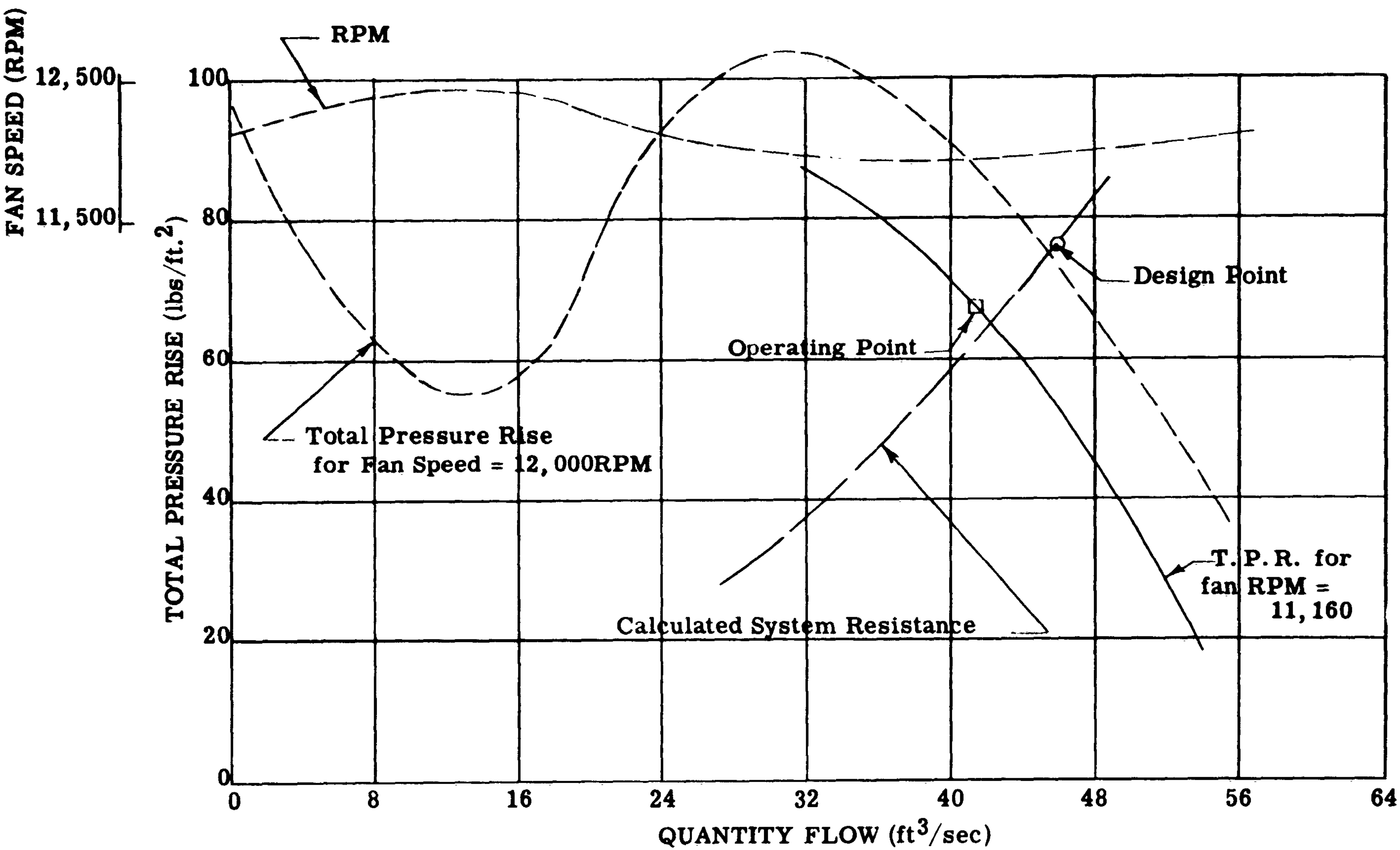


Figure 6

MODEL 319A

TOTAL TAKE-OFF DISTANCE OVER 50 FT. OBSTACLE

vs.

GROSS WEIGHT

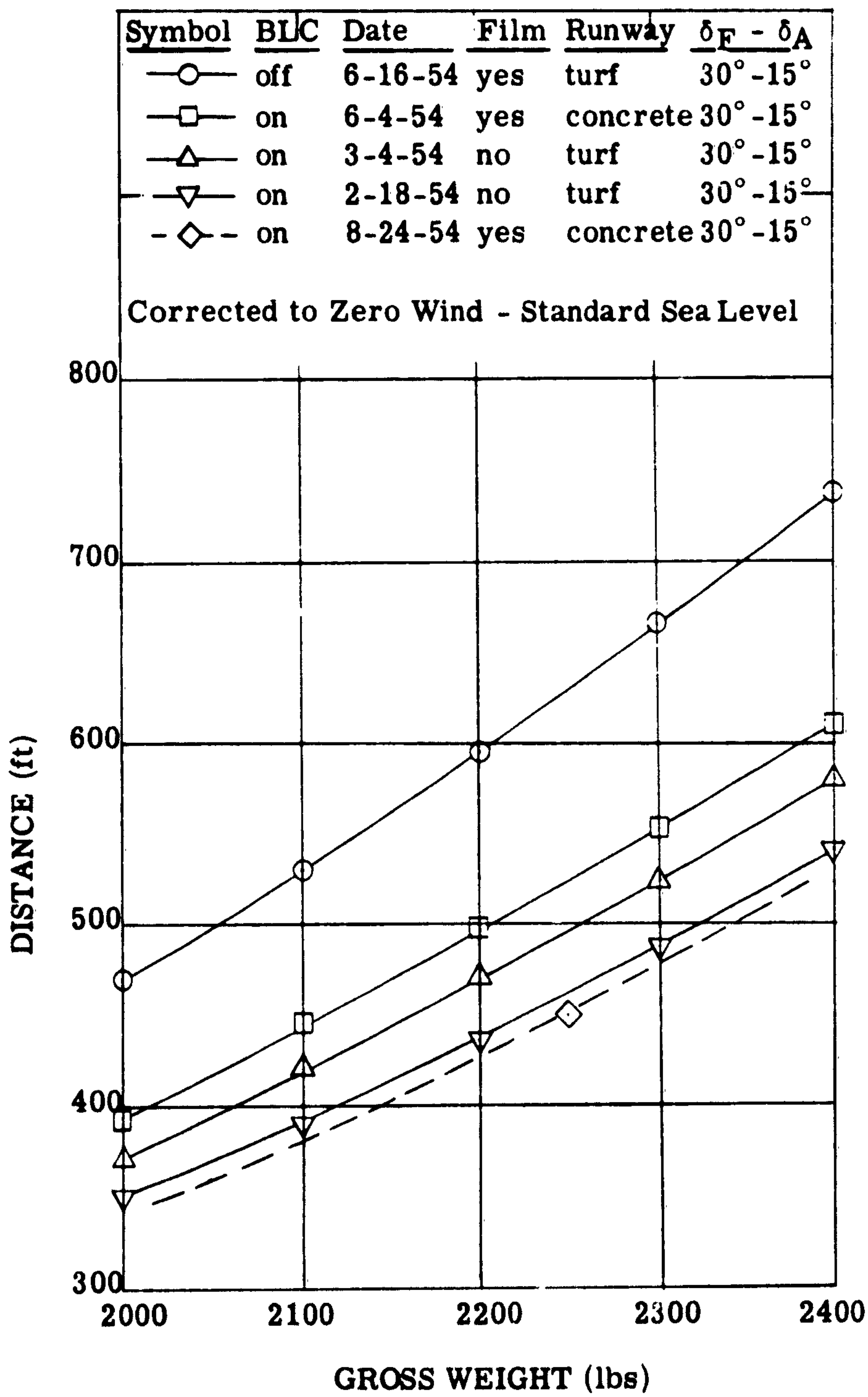


Figure 7

MODEL 319A
TOTAL LANDING DISTANCE OVER 50 FT. OBSTACLE
vs.
GROSS WEIGHT

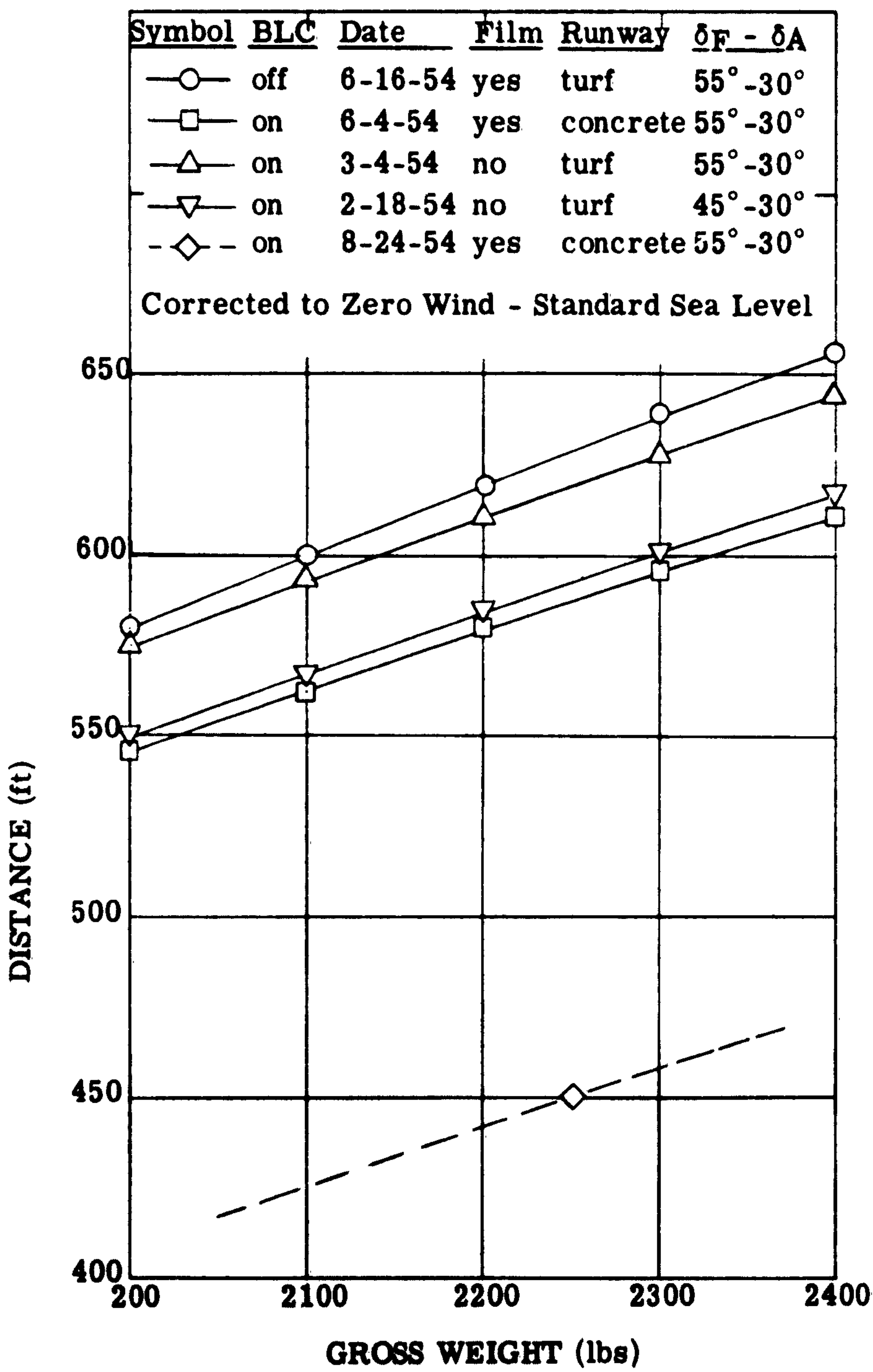


Figure 8

MODEL 319A
ESTIMATED LANDING PERFORMANCE
WITH SURFACE WIND

Gross Wt. = 2250 lbs.

$\delta_F = 55° - \delta_A = 30°$

BLC-on

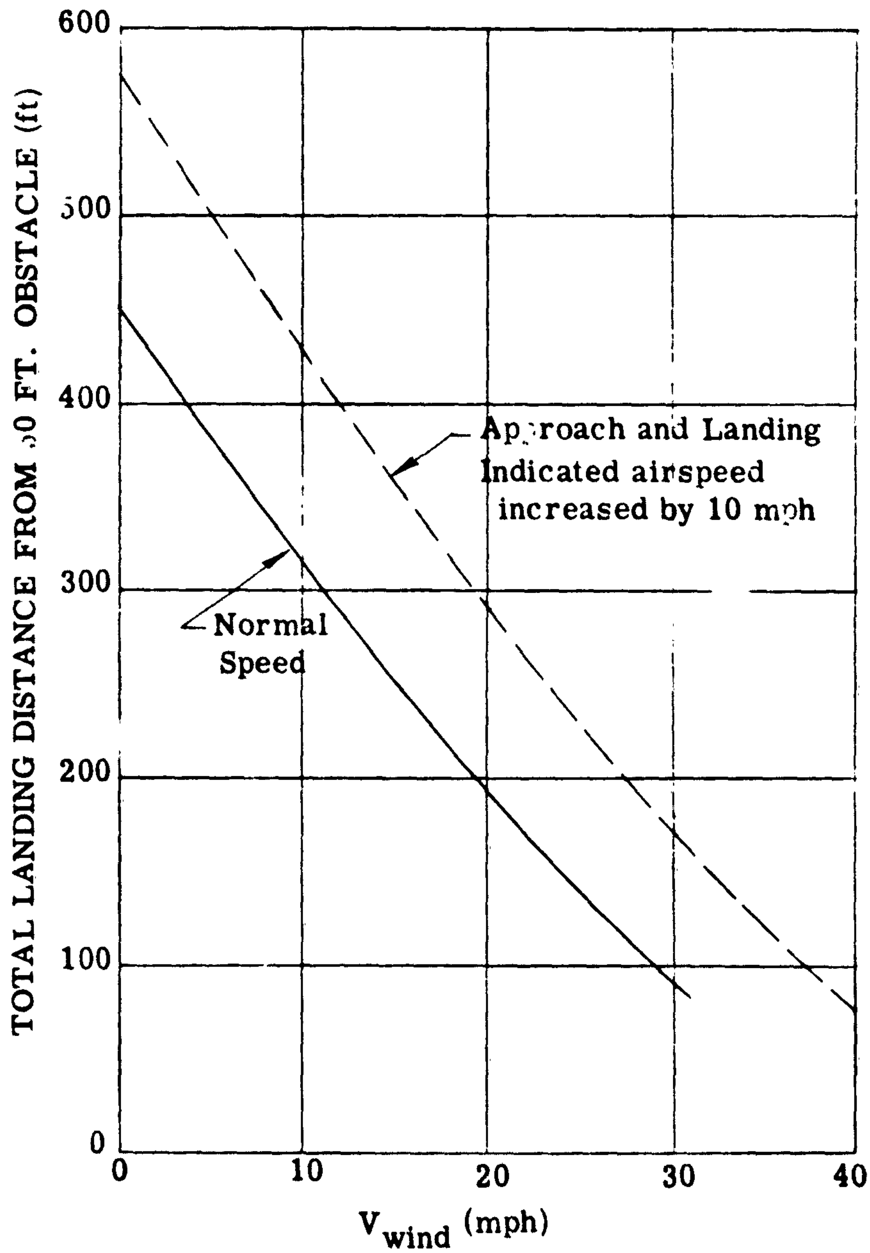


Figure 9

MODEL 319A
MAXIMUM RATE OF CLIMB vs. EQUIVALENT ALTITUDE
FULL THROTTLE

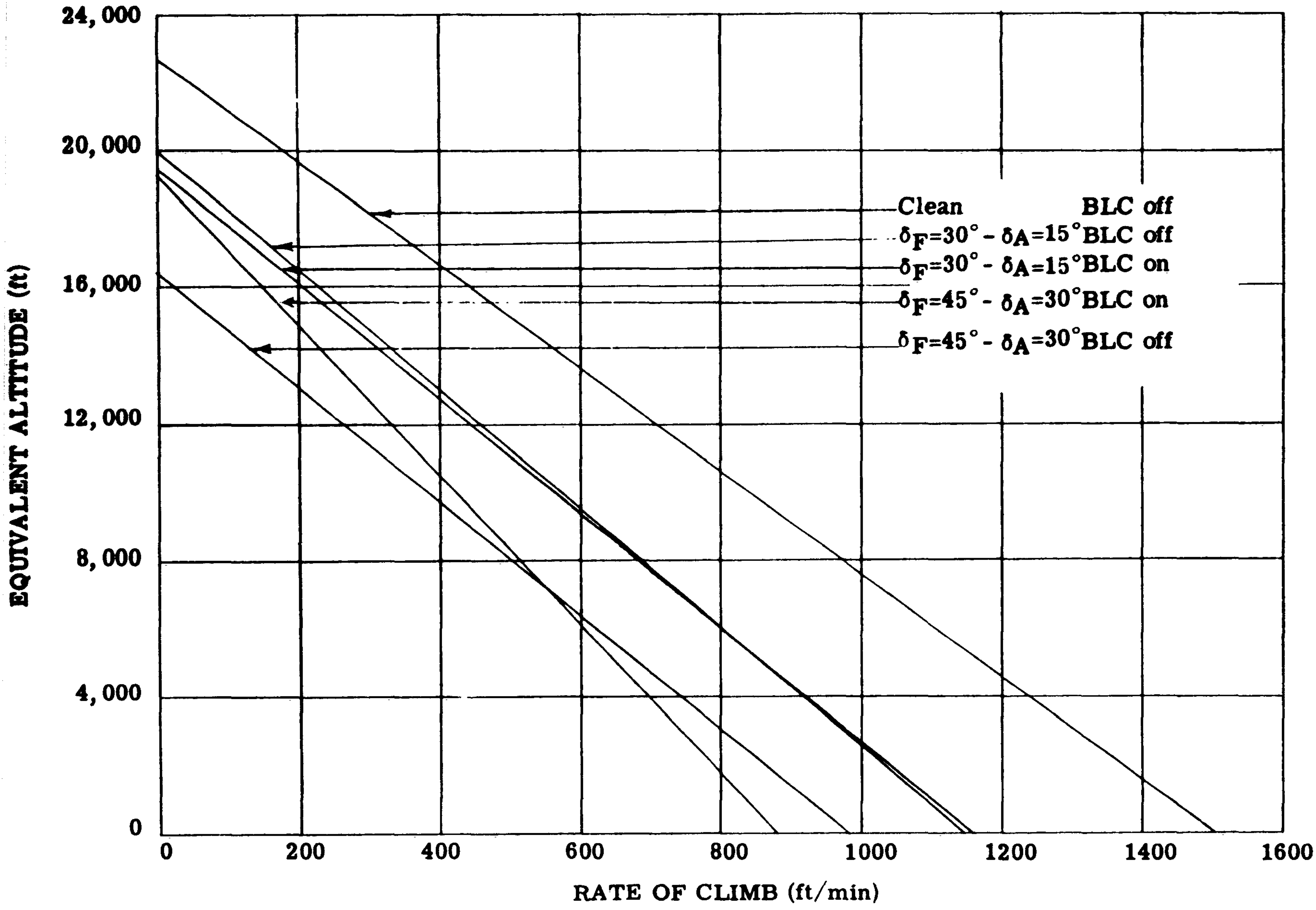


Figure 10

MODEL 319A
AIRPLANE LIFT CURVES
FULL THROTTLE

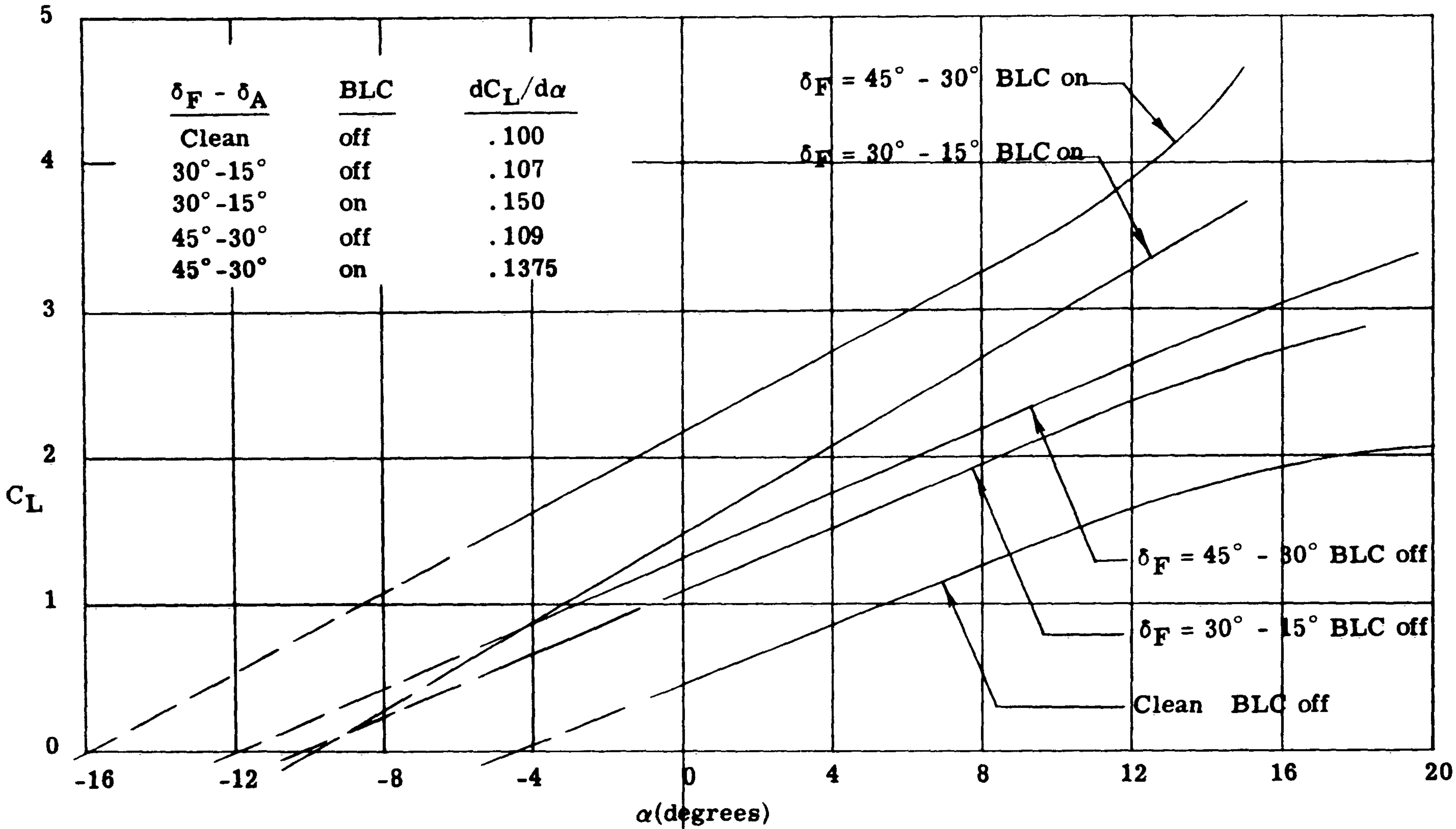


Figure 11

MODEL 319A
L/D vs. C_L
FULL THROTTLE

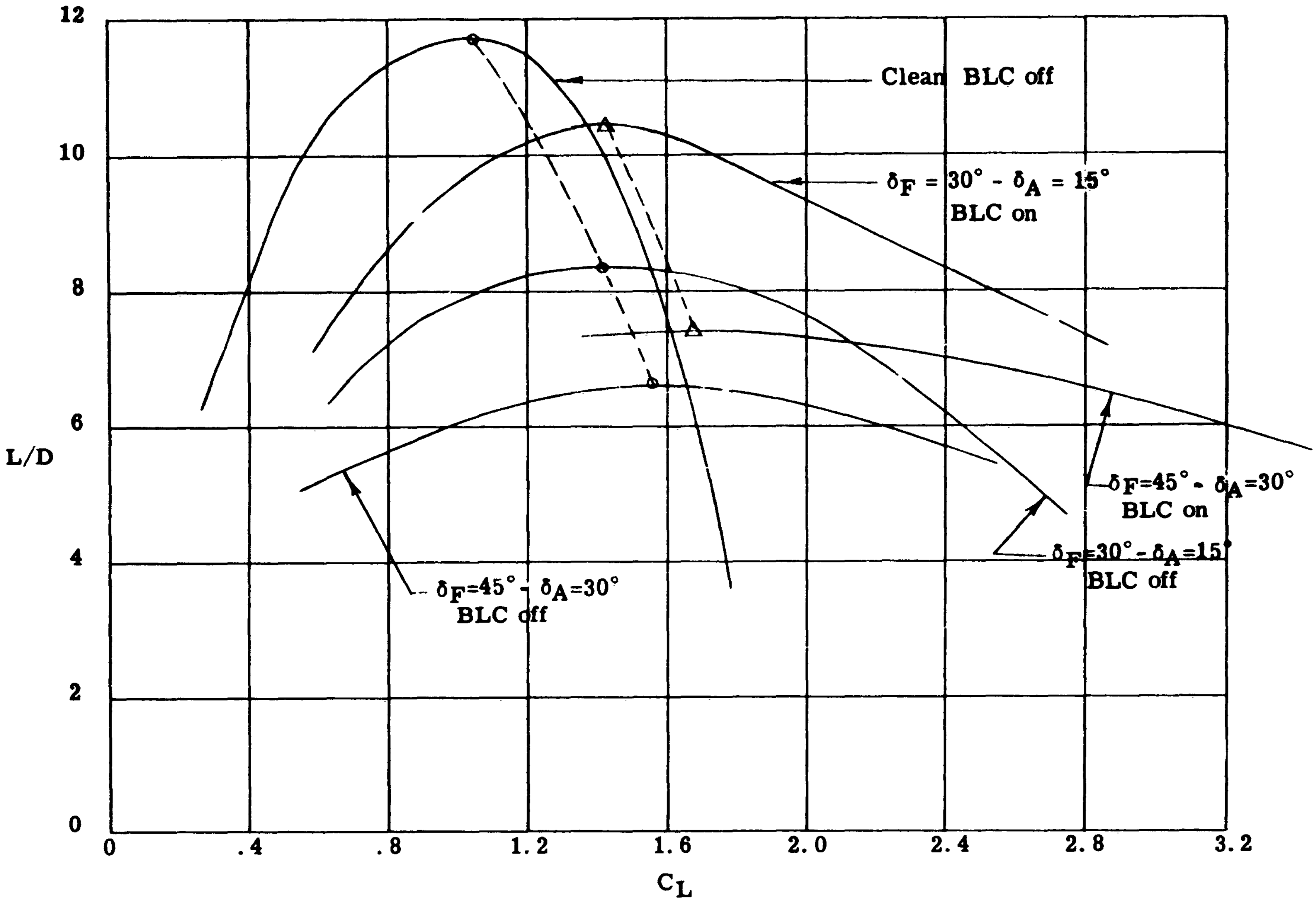


Figure 12

MODEL 319A
AIRPLANE DRAG POLARS
FULL THROTTLE

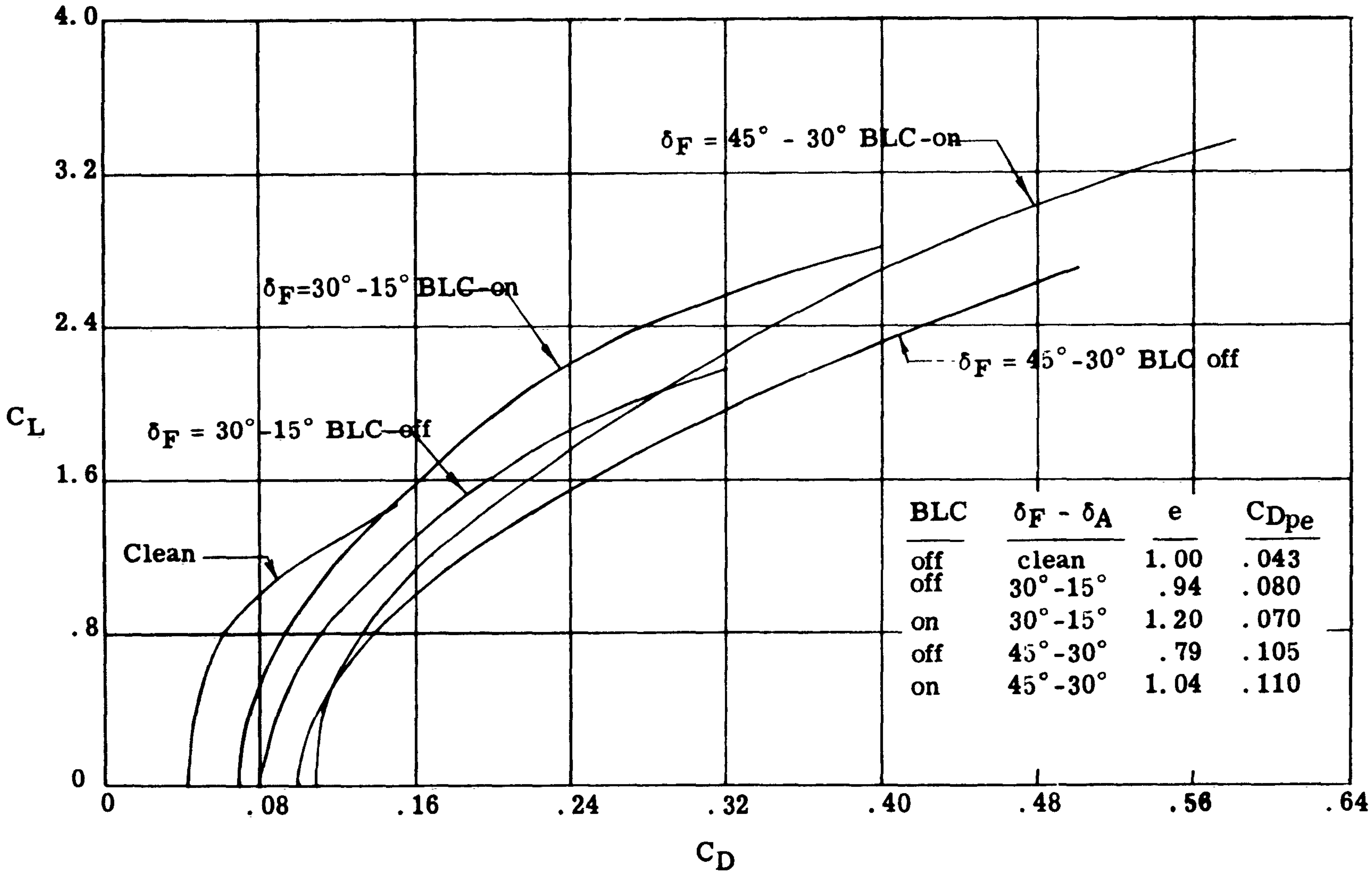


Figure 13

MODEL 319A

C_L vs. α

FEATHERED PROPELLER

BLC OFF

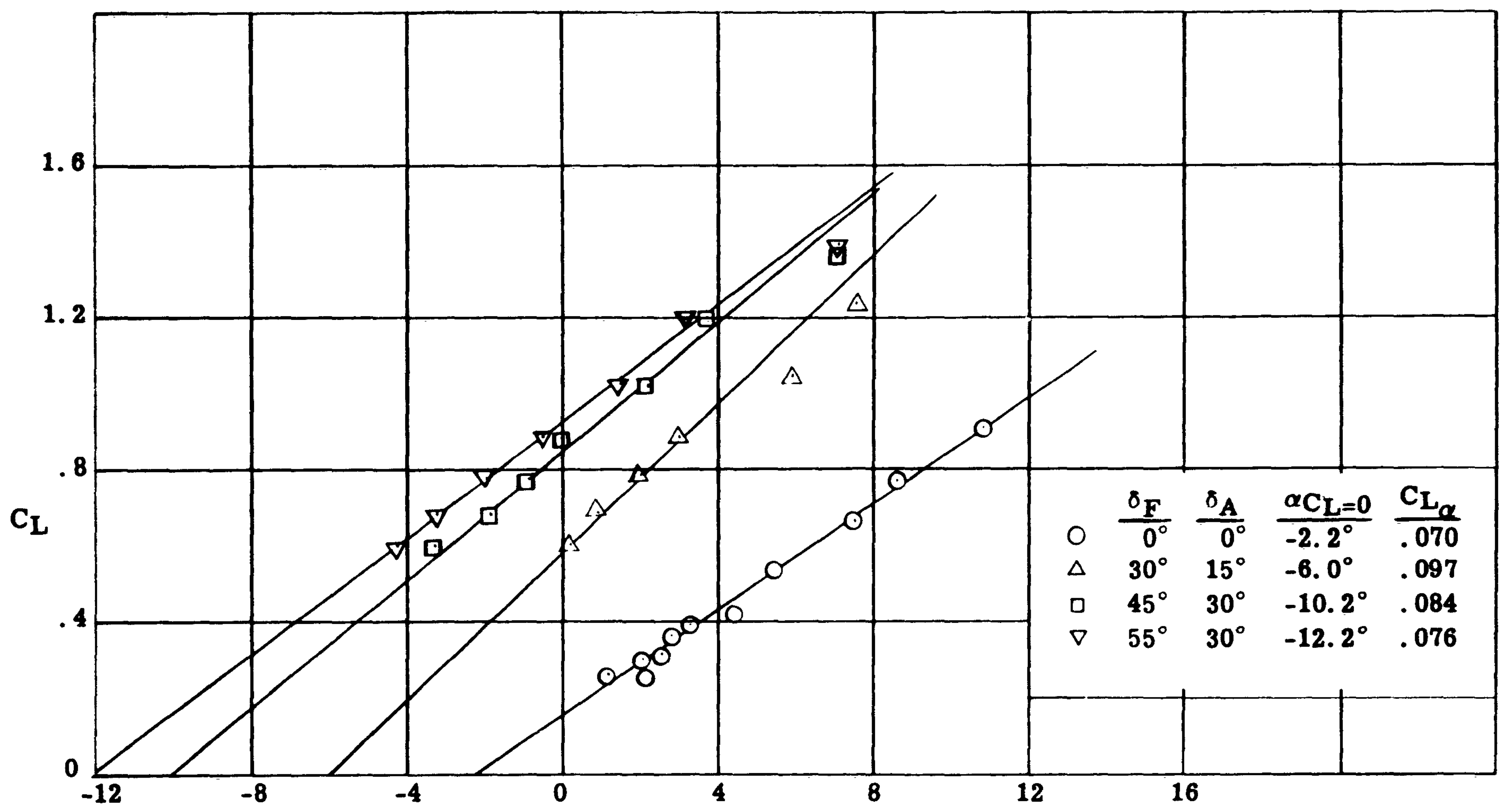


Figure 14

MODEL 319A
L/D vs. C_L
BLC System Off   Feathered Propeller

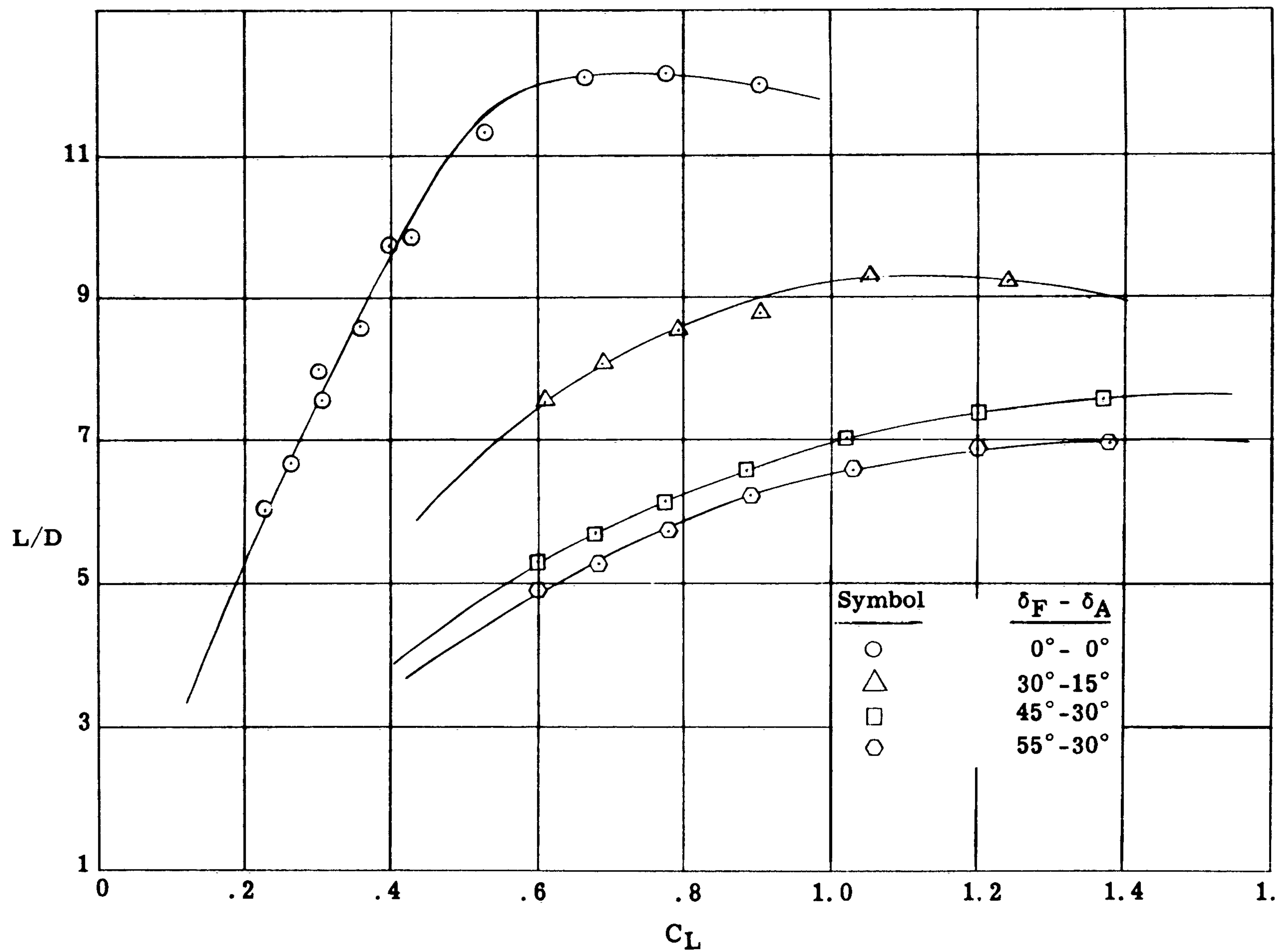


Figure 15

MODEL 319A
AIRPLANE DRAG POLARS
Feathered Propeller
BLC-off

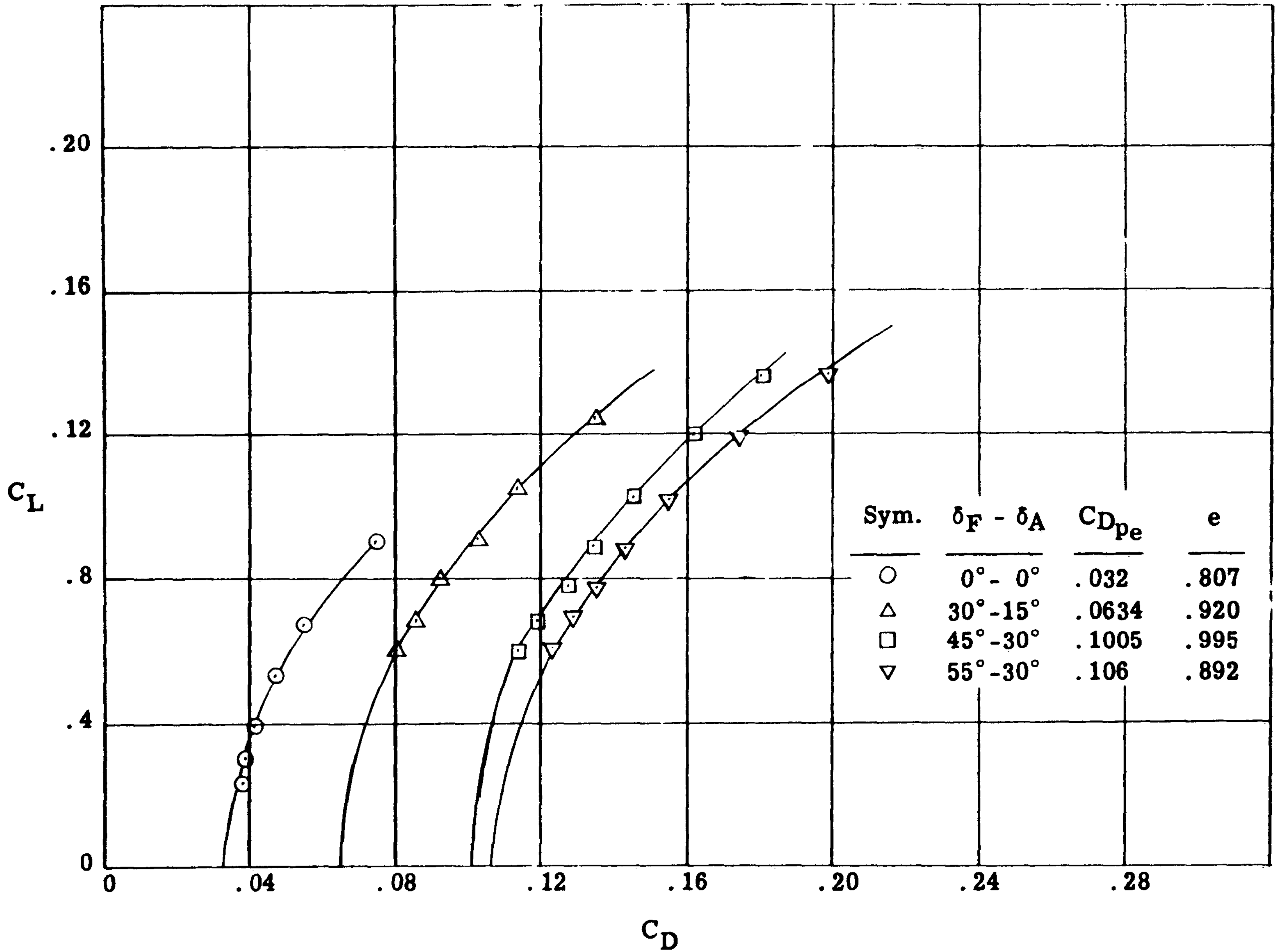


Figure 16

MODEL 319A

C_L vs. α

$\delta_F = 55^\circ \quad \delta_A = 30^\circ$

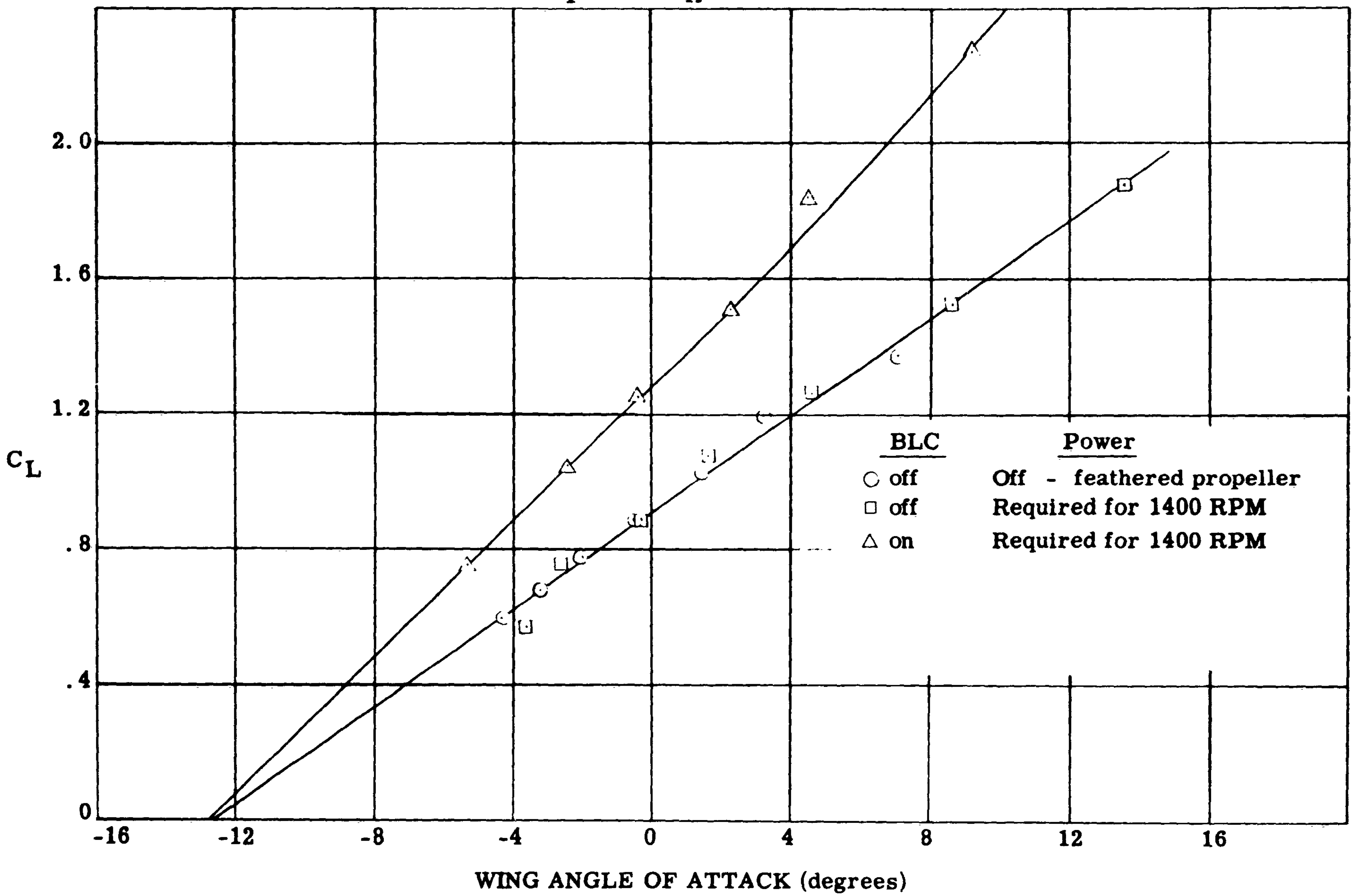
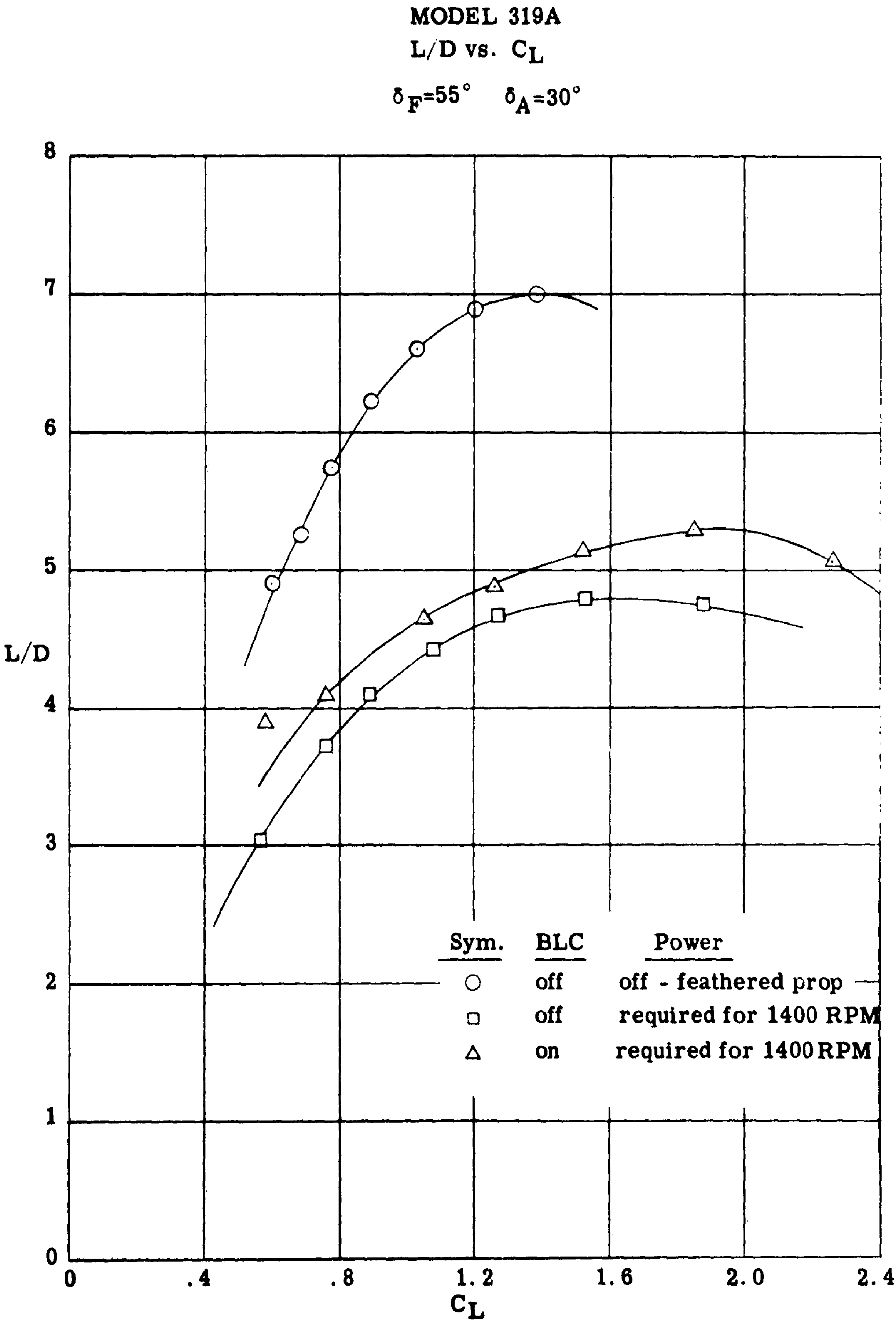


Figure 17



MODEL 319A
L/D vs. C_L
$\delta_F=55°$ $\delta_A=30°$
L/D
0
1
2
3
4
5
6
7
8
0
.4
.8
1.2
1.6
2.0
2.4
C_L
Sym. BLC Power
○ off off - feathered prop
□ off required for 1400 RPM
△ on required for 1400 RPM

Figure 18

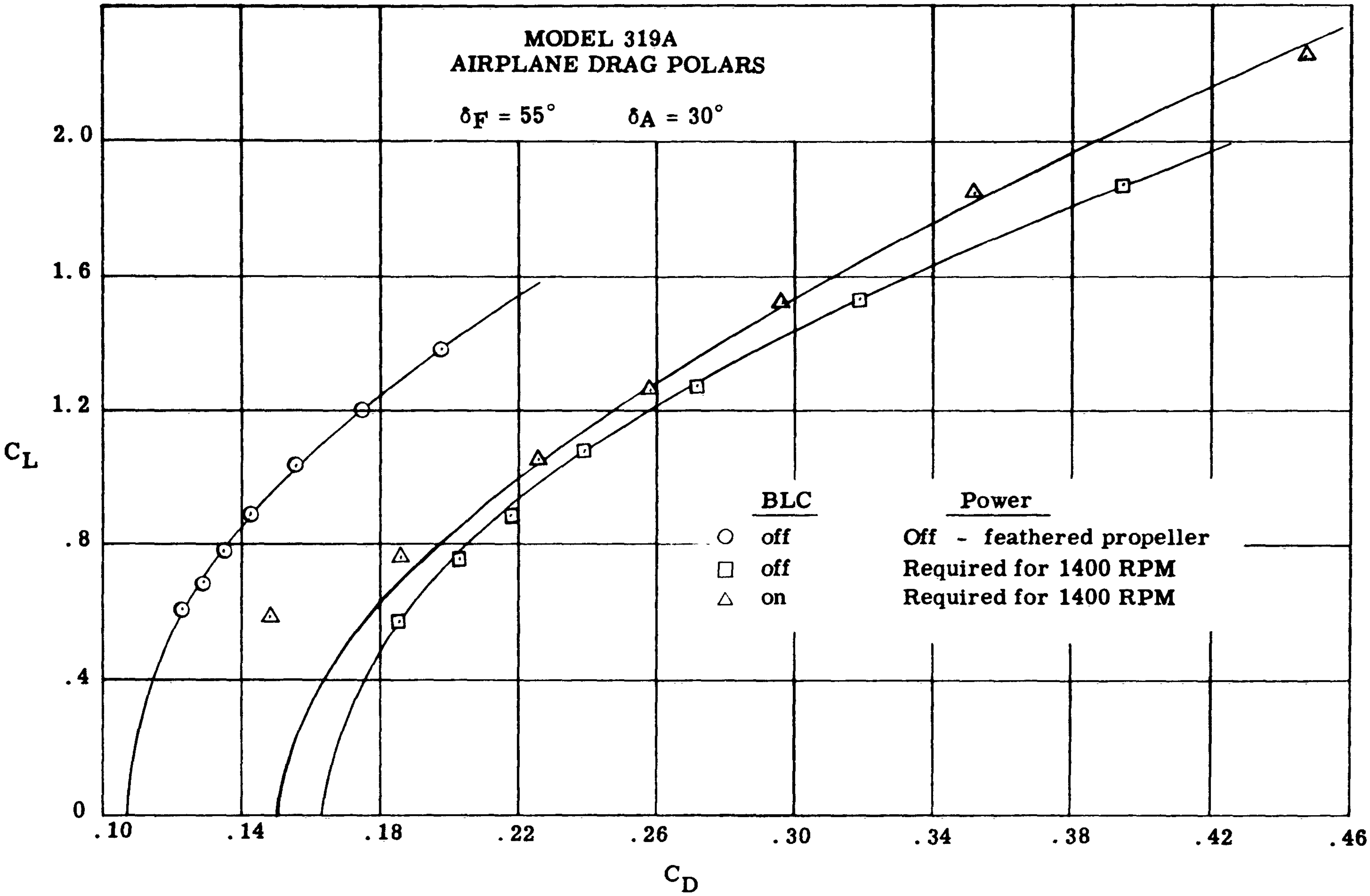

MODEL 319A
AIRPLANE DRAG POLARS
$\delta_F = 55°$ $\delta_A = 30°$
BLC
Power
○ off Off - feathered propeller
□ off Required for 1400 RPM
△ on Required for 1400 RPM
C_L
2.0
1.6
1.2
.8
.4
0
C_D
.10
.14
.18
.22
.26
.30
.34
.38
.42
.46

Figure 19

MODEL 319A

$\delta_F=45^\circ$ $\delta_A=30^\circ$

LANDING PITCH ATTITUDE AND ELEVATOR DEFLECTION REQUIRED TO 3-POINT vs. C. G. LOCATION

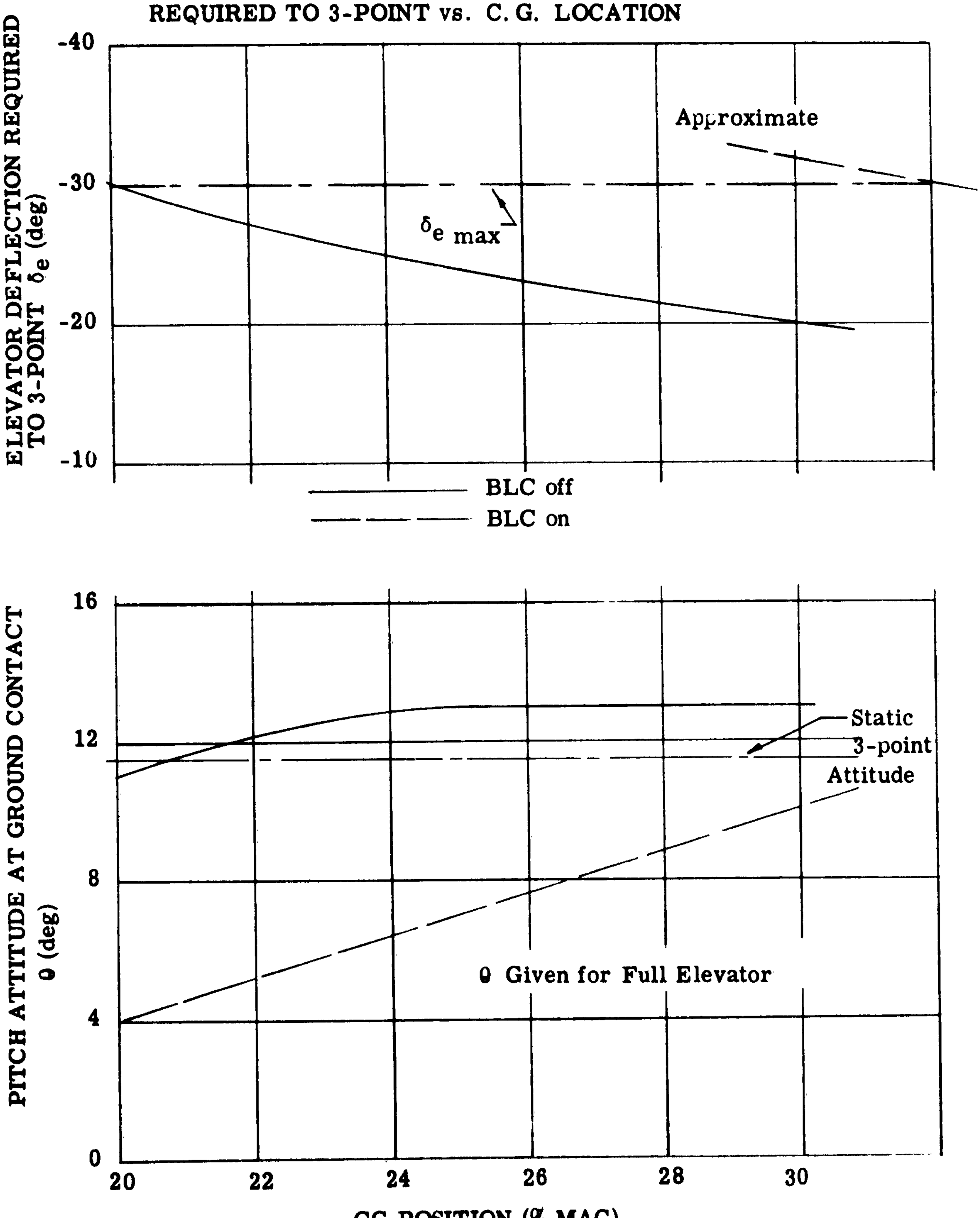


Figure 20

MODEL 319A

LANDING PITCH ATTITUDE, ELEVATOR DEFLECTION AND STICK FORCE

vs.

TIME

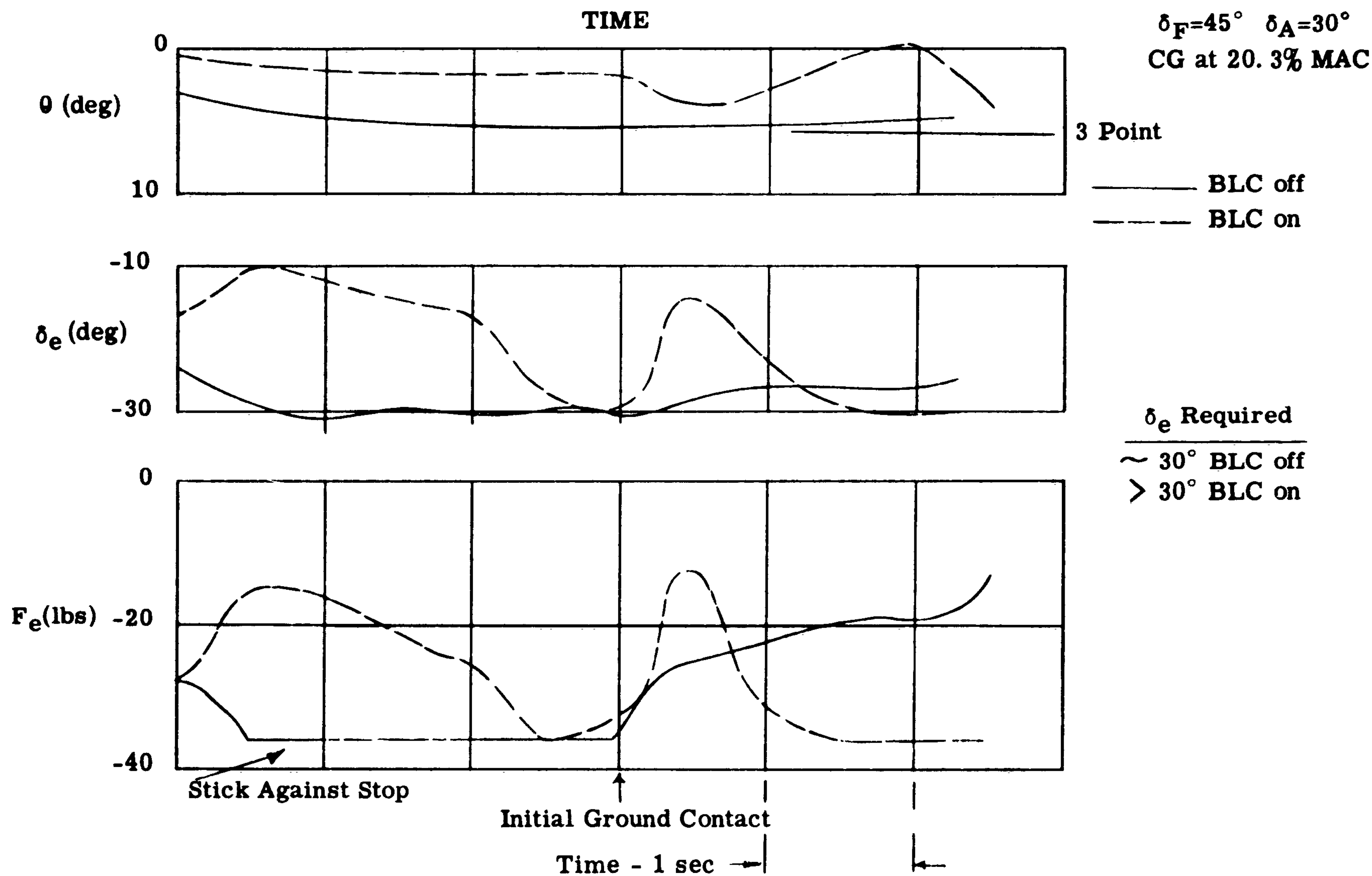


Figure 21

MODEL 319A

LIMIT FORWARD C. G. LOCATION

$\delta_F = 45^\circ \quad \delta_A = 30^\circ$

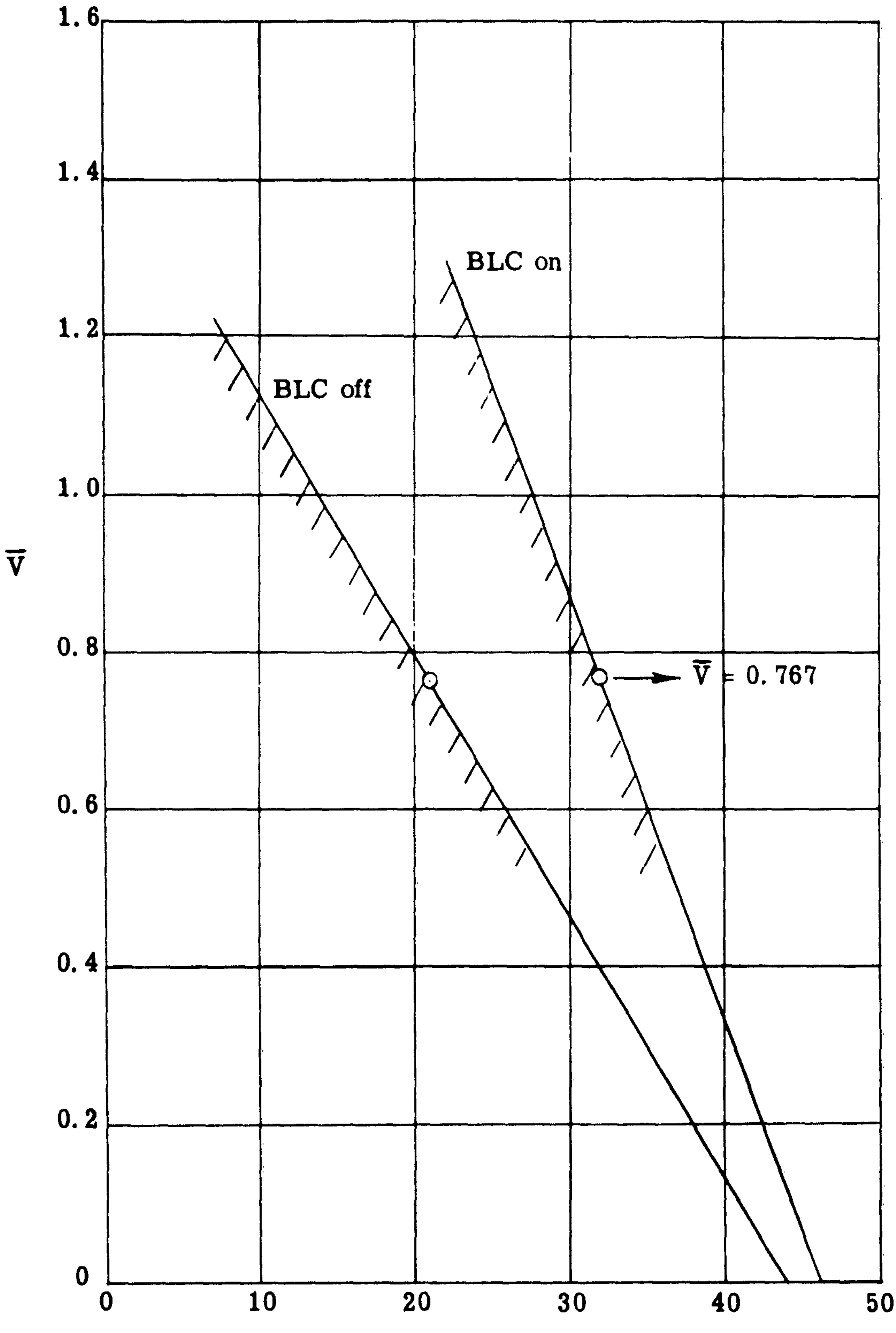


Figure 22

MODEL 319A
LONGITUDINAL TRIM
VELOCITY vs. STABILIZER INCIDENCE
C. G. at 20.25% MAC

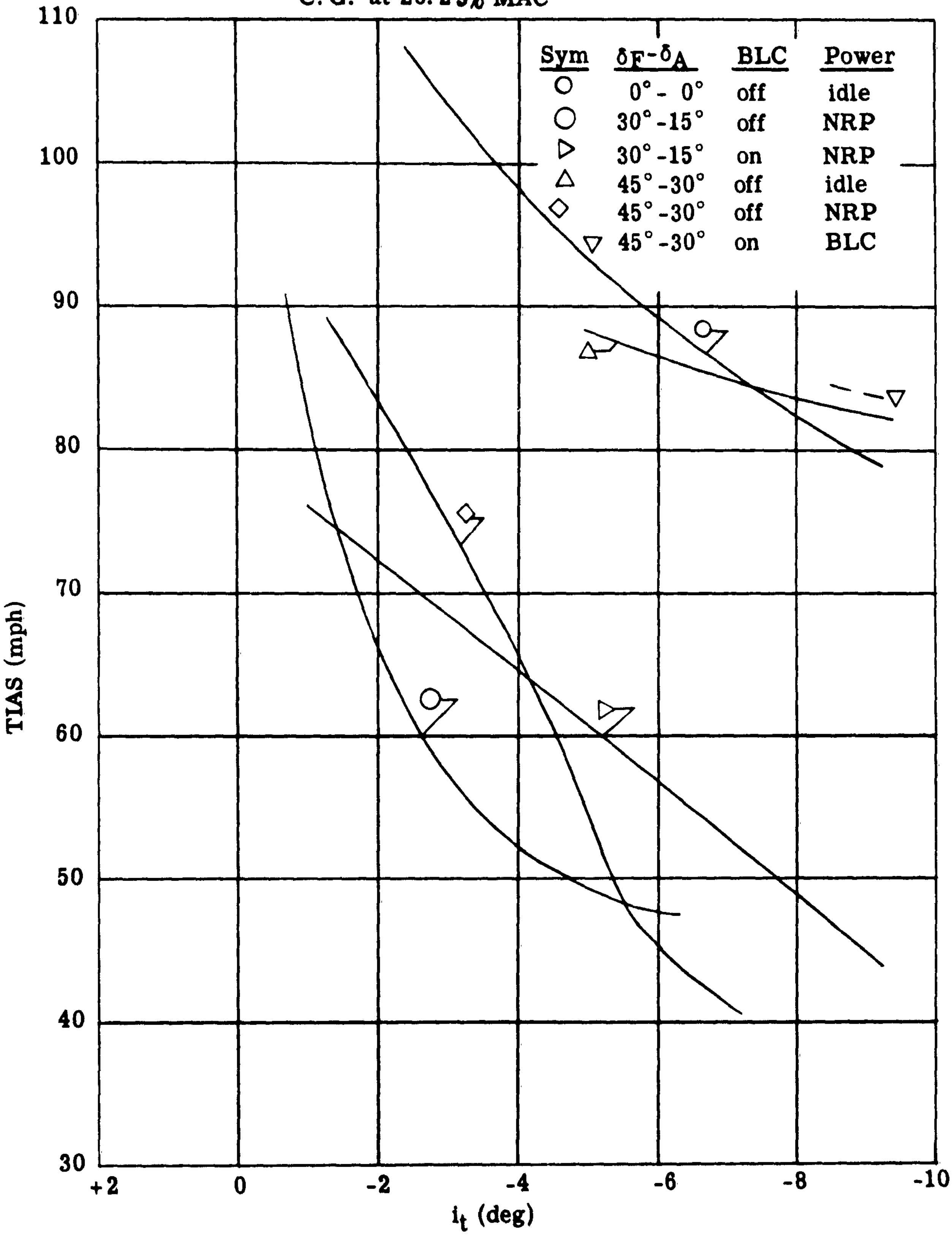


Figure 23

MODEL 319A
LONGITUDINAL TRIM
VELOCITY vs. STABILIZER INCIDENCE
C. G. at 30% MAC

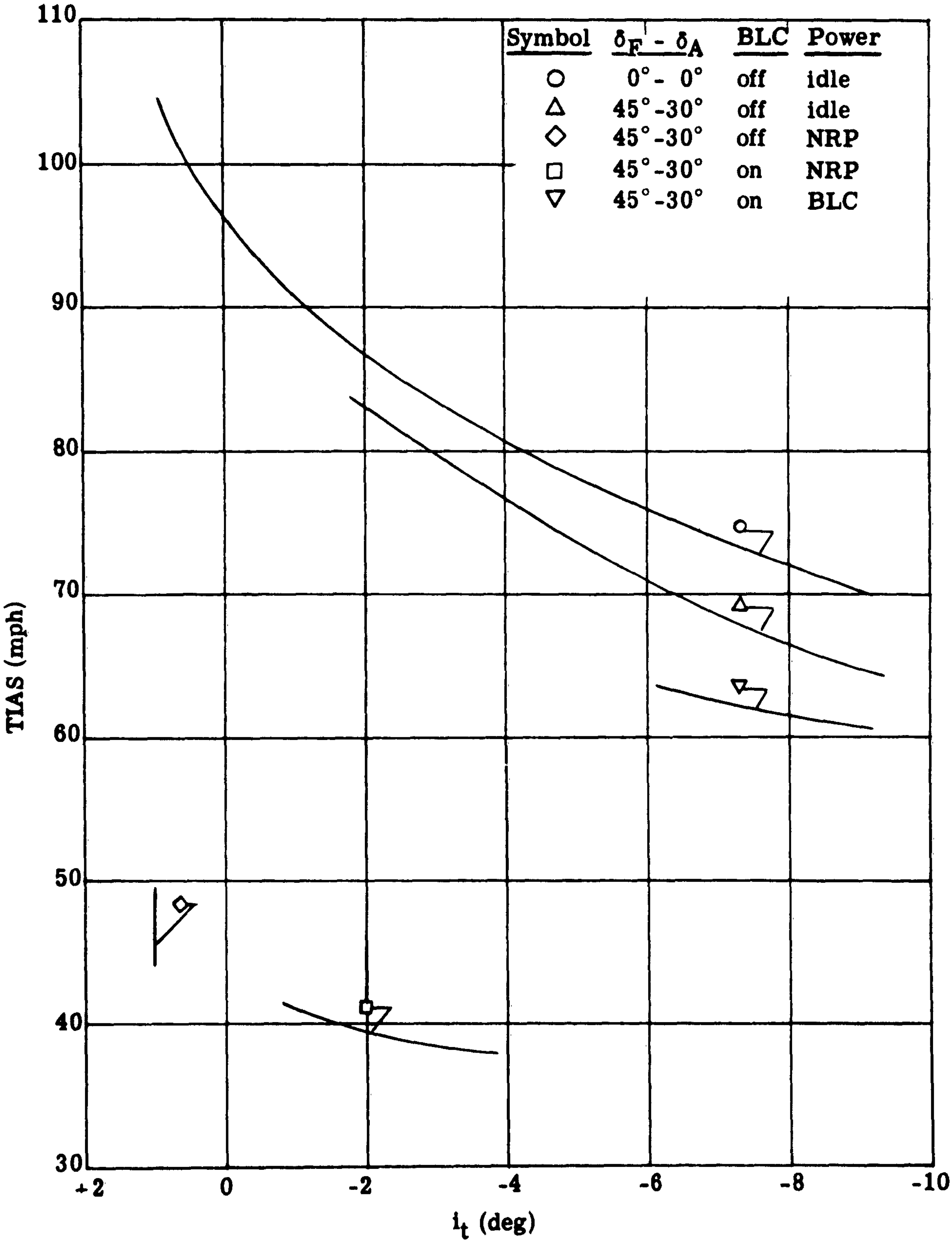


Figure 24

MODEL 319A
STICK FORCE AND ELEVATOR DEFLECTION
vs. NORMAL ACCELERATION
C. G. at 20.25% MAC Alt. 5000 ft.

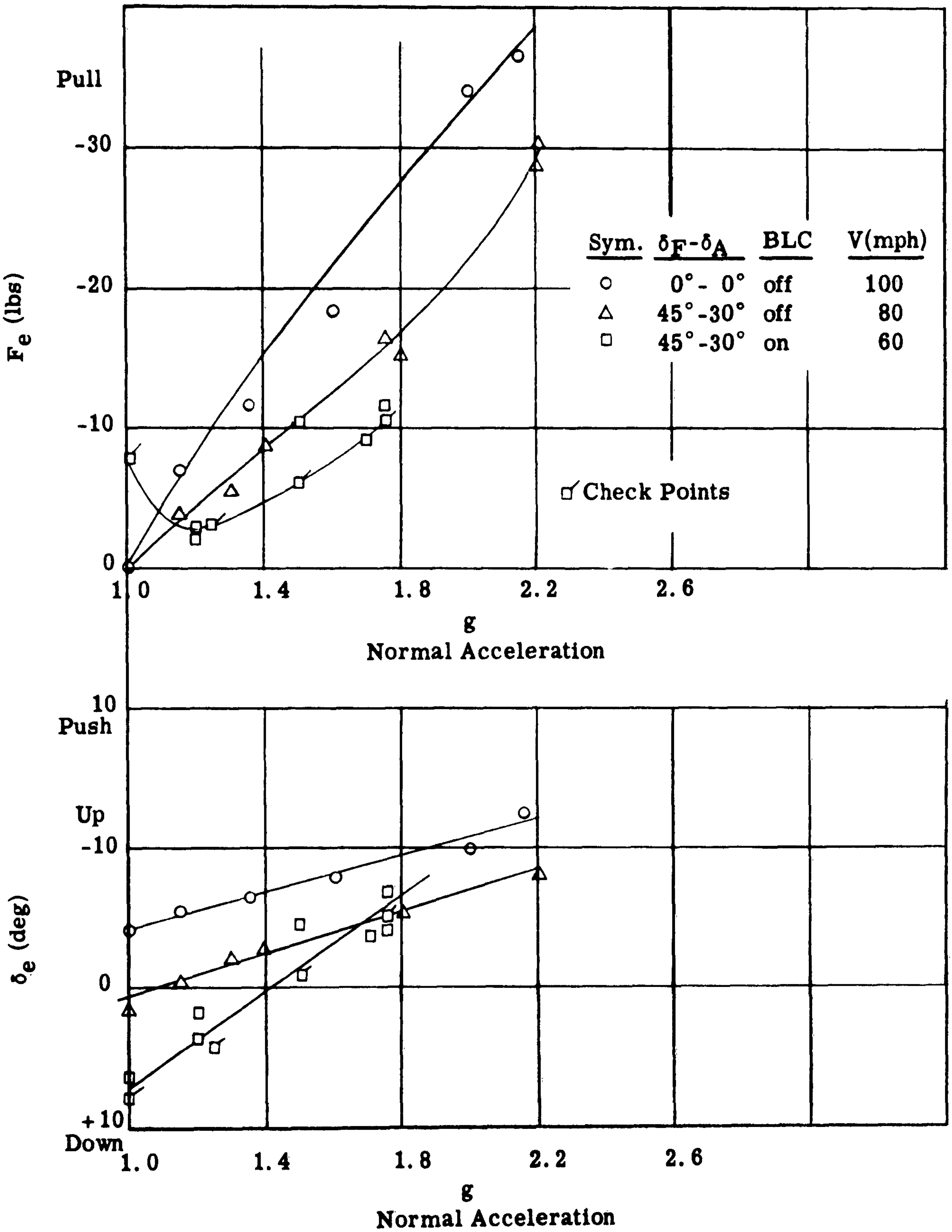


Figure 25

MODEL 319A
MANEUVERING STICK FORCES
STICK FORCE vs. NORMAL ACCELERATION
CG at 20.25% MAC

δ_F - δ_A	BLC	V(mph)
45°-30°	on	60

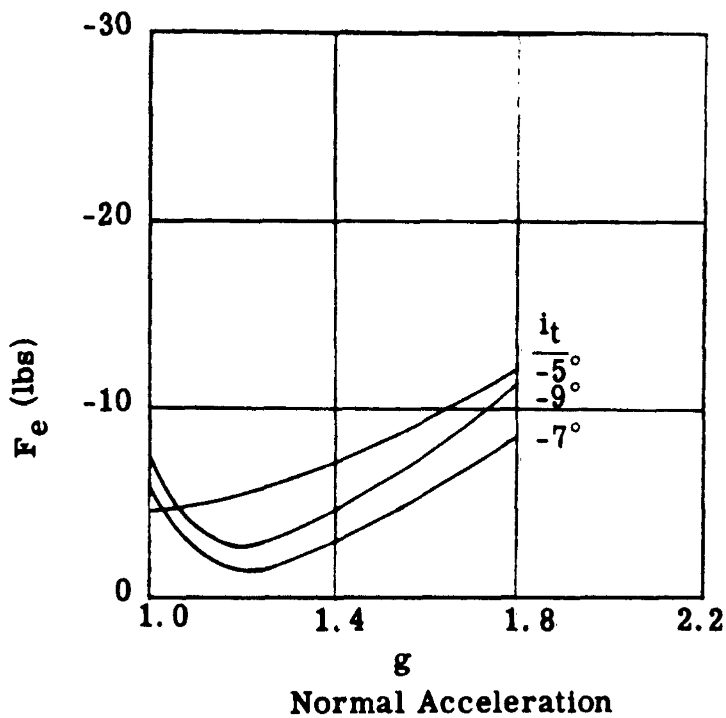


Figure 26

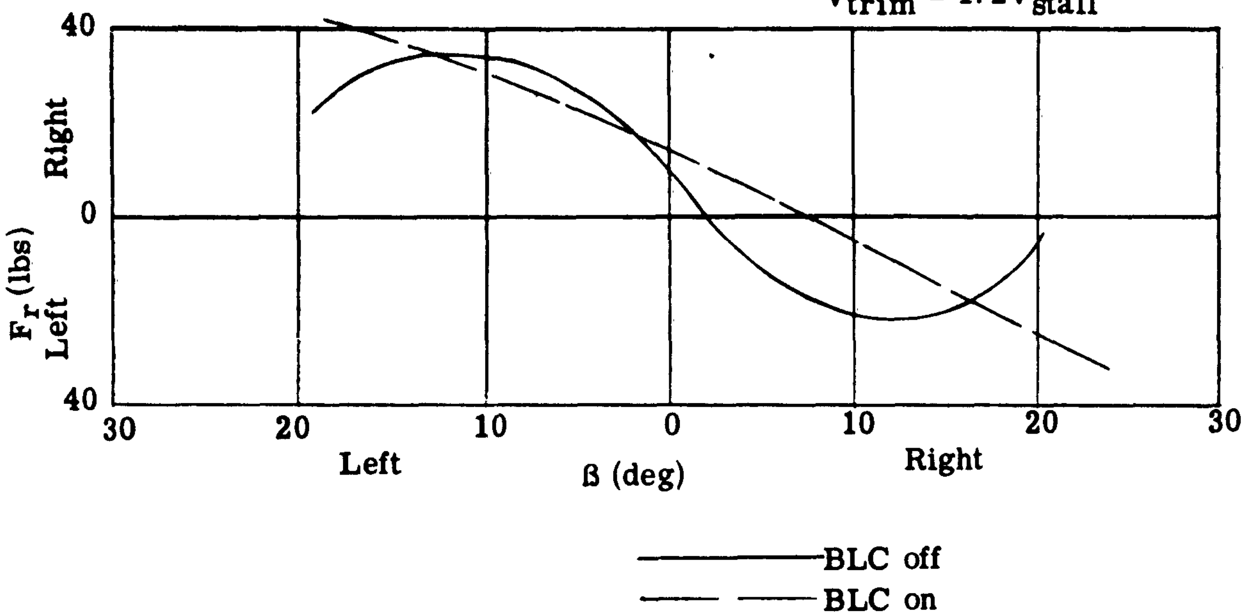
MODEL 319A

RUDDER DEFLECTION AND STICK FORCE

vs.

SIDESLIP ANGLE

$\delta_F = 45°$ $\delta_A = 30°$
Normal Rated Power
$V_{trim} = 1.2V_{stall}$



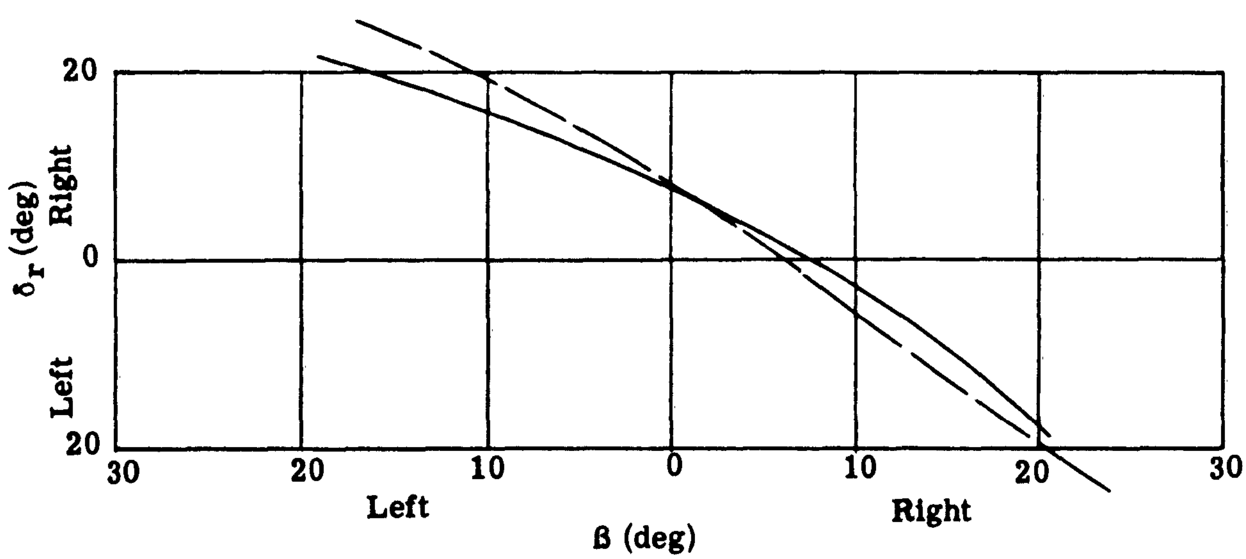


Figure 27

MODEL 319A

pb/2V vs. TOTAL AILERON DEFLECTION

Aileron Roll - Rudder Fixed

$\delta_F = 45°$ $\delta_A = 30°$ Power for Level Flight

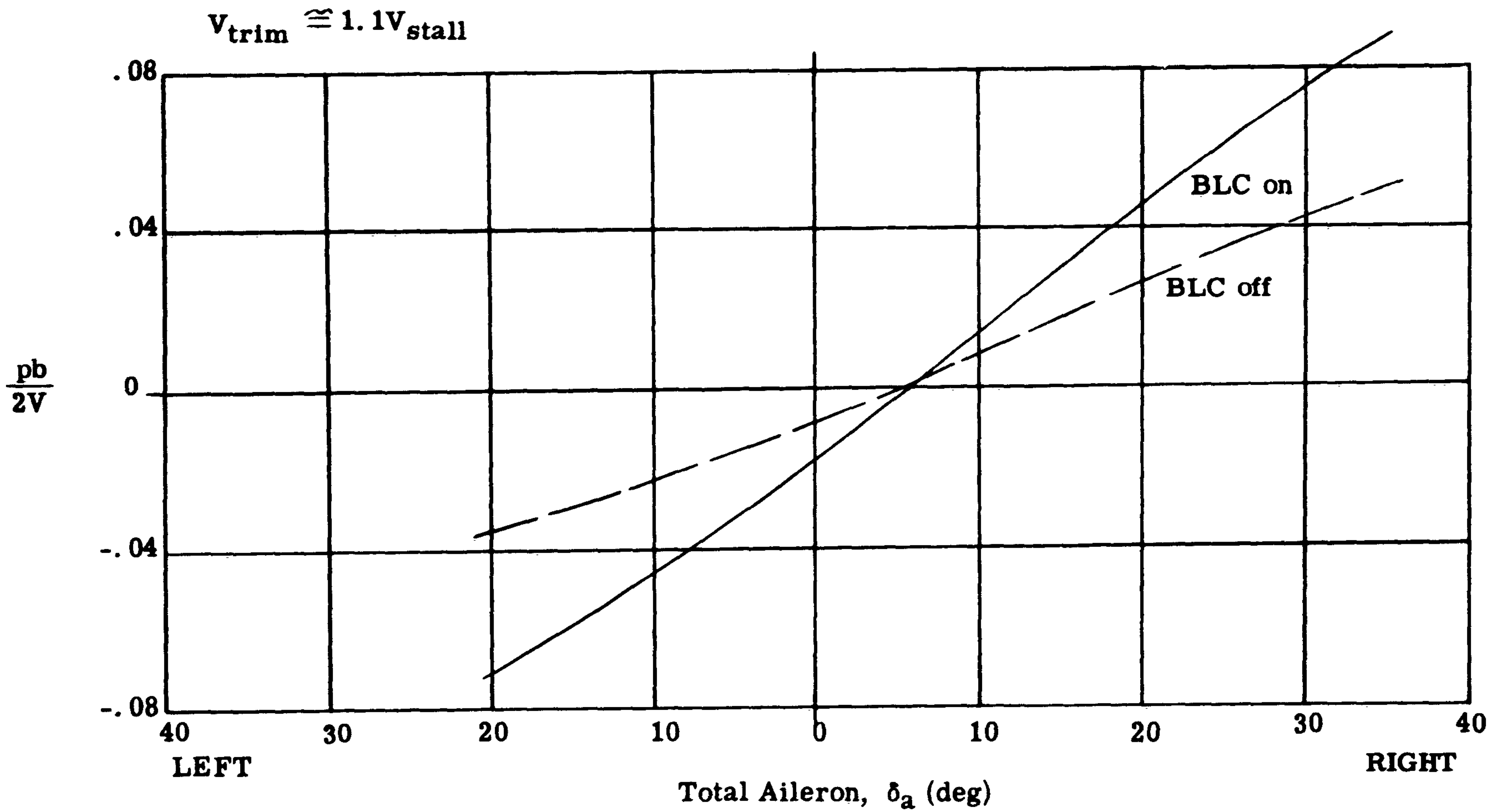


Figure 28

MODEL 319A

pb/2V vs. TOTAL AILERON DEFLECTION

Aileron Roll - Rudder Fixed

$\delta_F = 45°$ Power for Level Flight

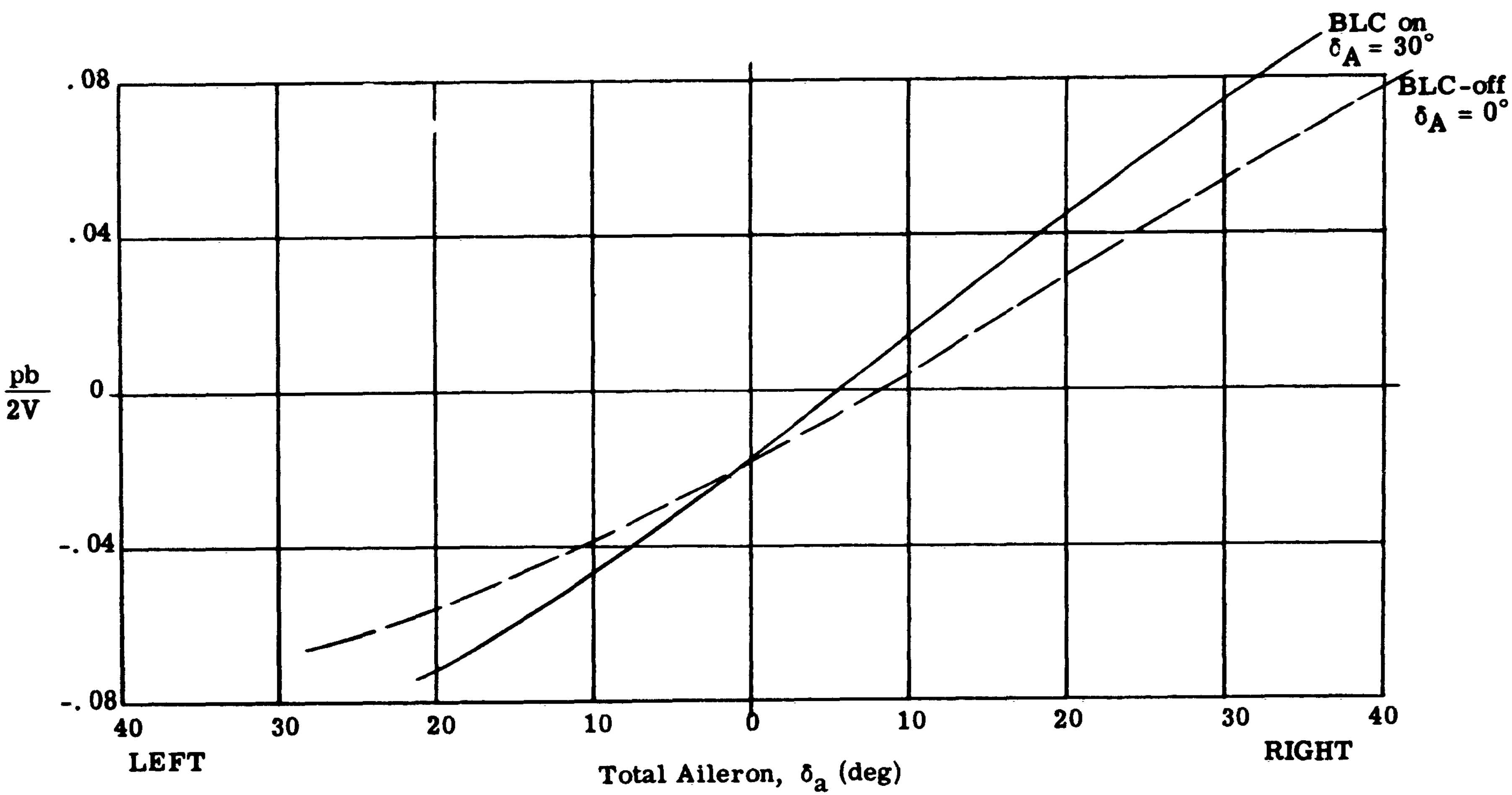


Figure 29

MODEL 319A
STALL DATA vs. TIME

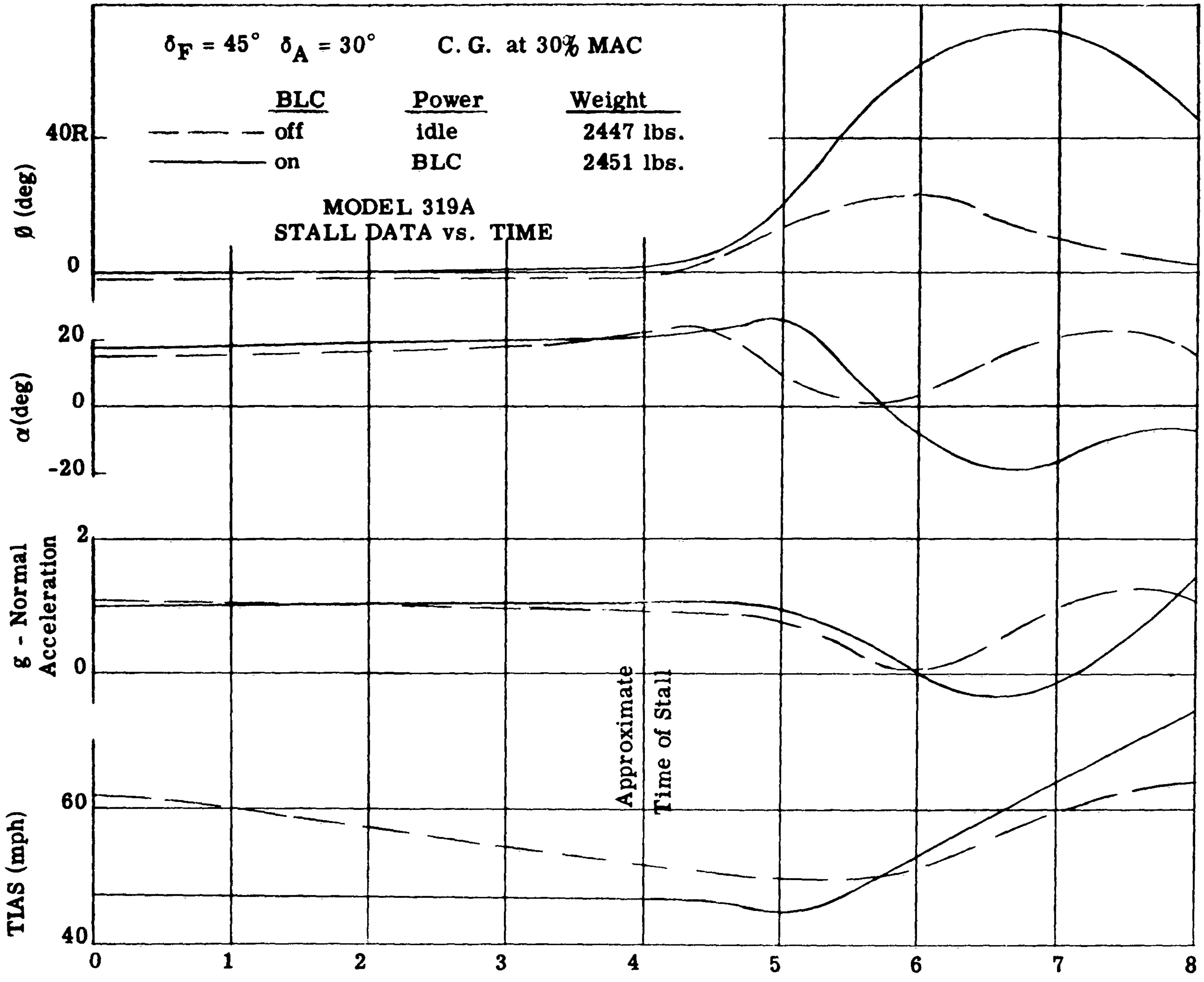


Figure 30

MODEL 319A

STALL DATA vs. TIME

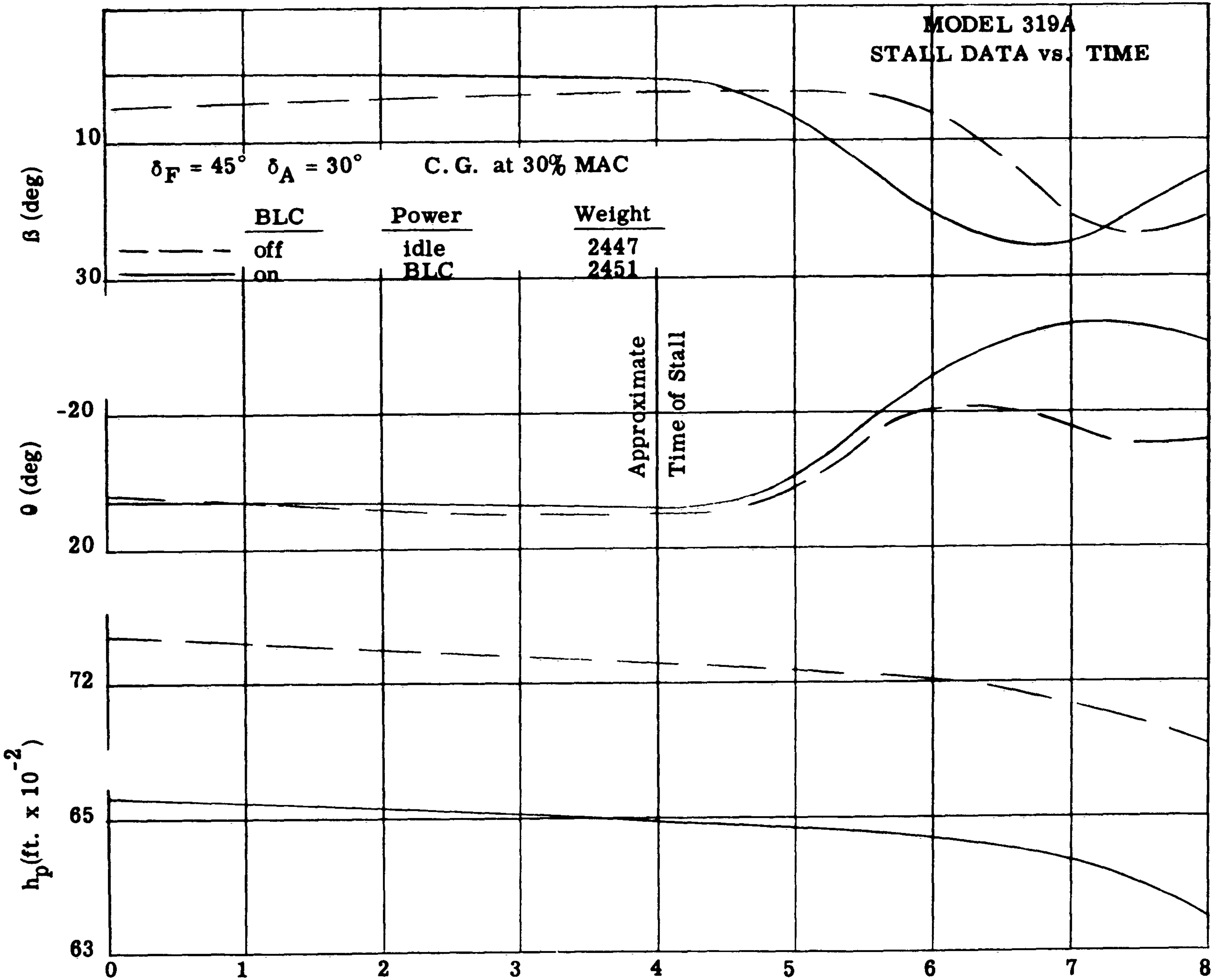


Figure 31

MODEL 319A

$C_{L_{max}}$ vs. C_{Q_B}

BASED ON UNIVERSITY OF WICHITA WIND TUNNEL DATA

$C_{Q_B} = Q/S_B V$ (Blowing Wing Area)

$S_B = 10.87$ ft.^{2}

q = 2.5 in. Alch.

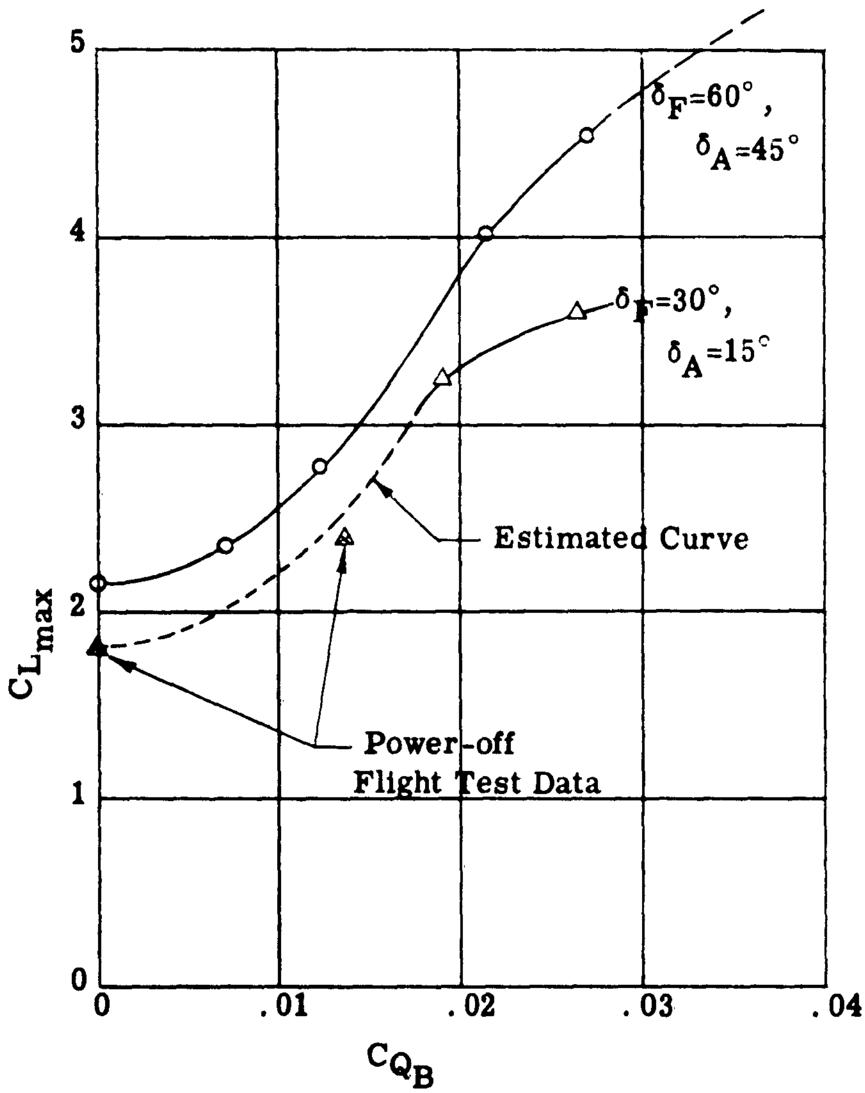


Figure 32

MODEL 319A

C_{Q_S} vs. C_L

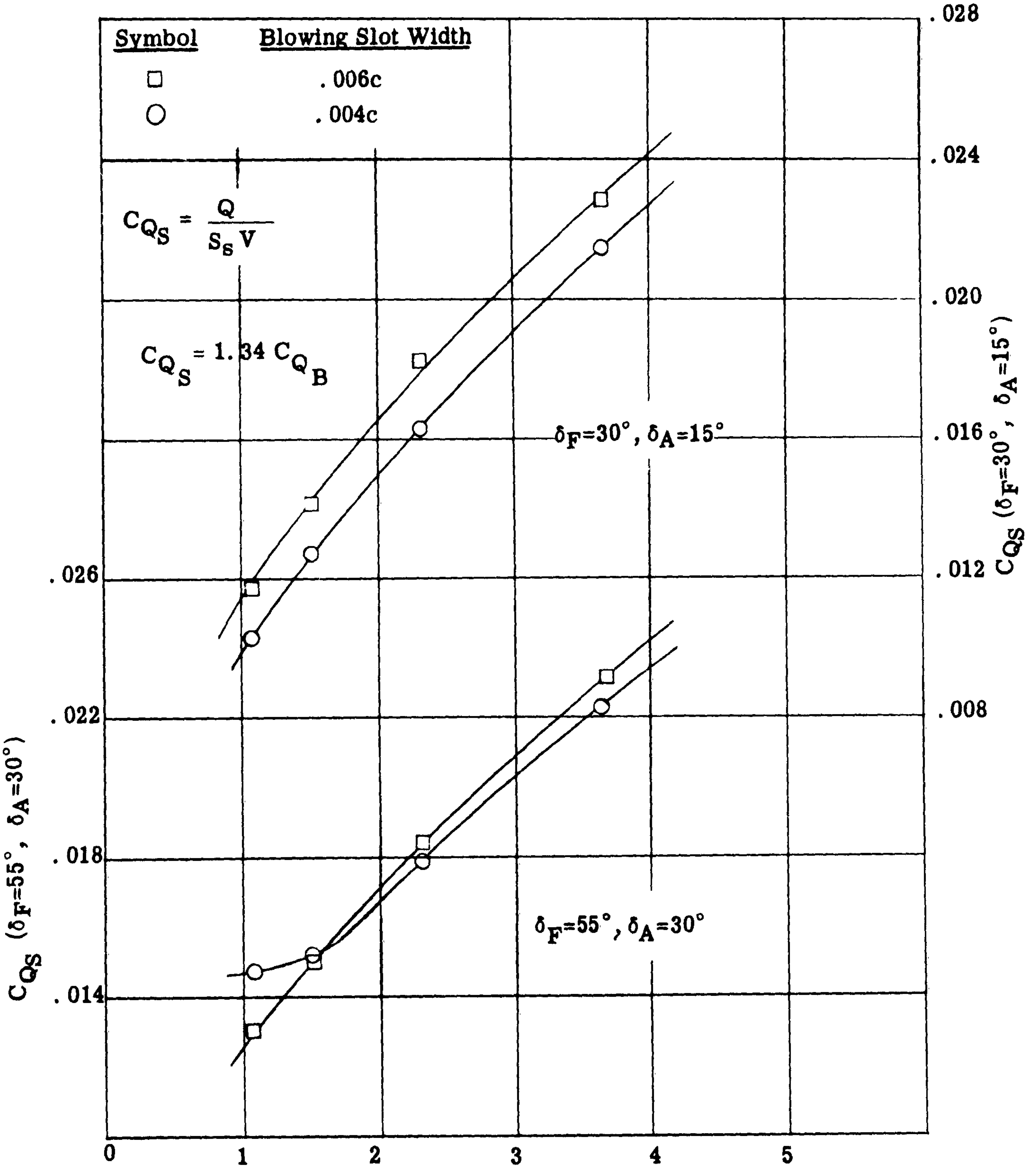


Figure 33

MODEL 319A
QUANTITY FLOW vs. VELOCITY

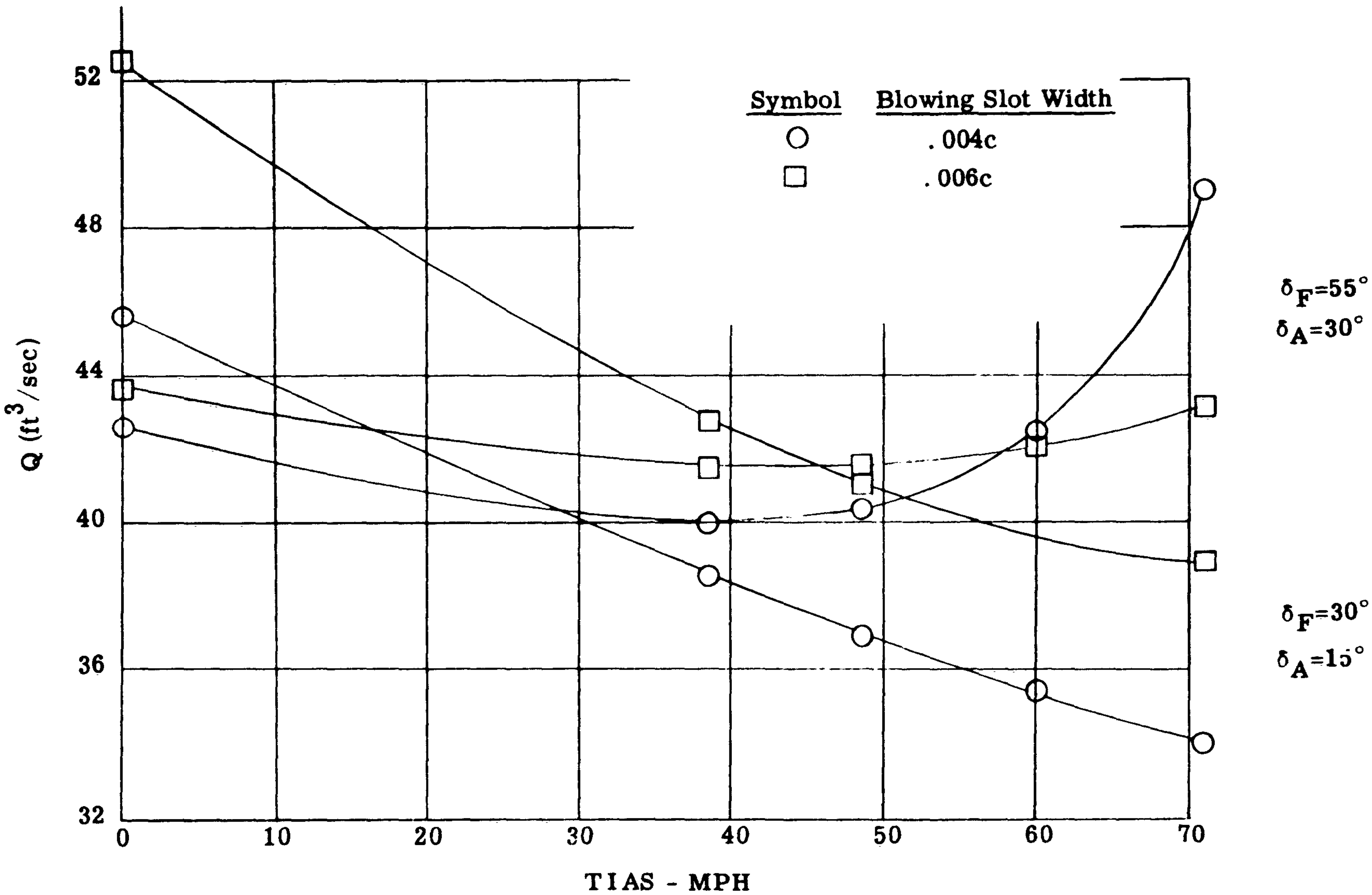
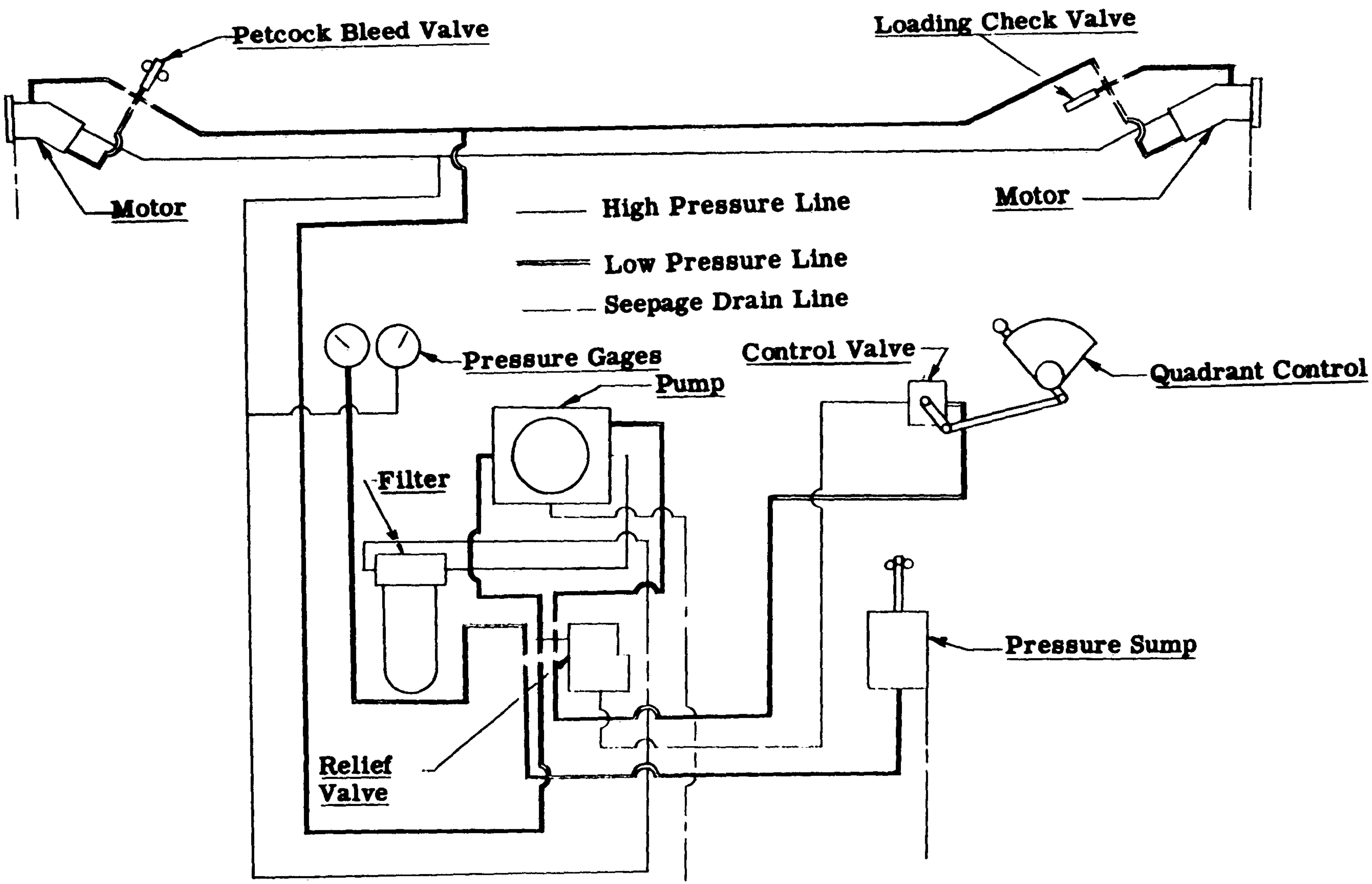


Figure 34



319A BLC HYDRAULIC SYSTEM

SCHEMATIC VIEW

Figure 35

MODEL 319A
PERFORMANCE CHARACTERISTICS
OF HYDRAULIC MOTOR
Vickers Hydraulic Motor
Model MF-3909-15

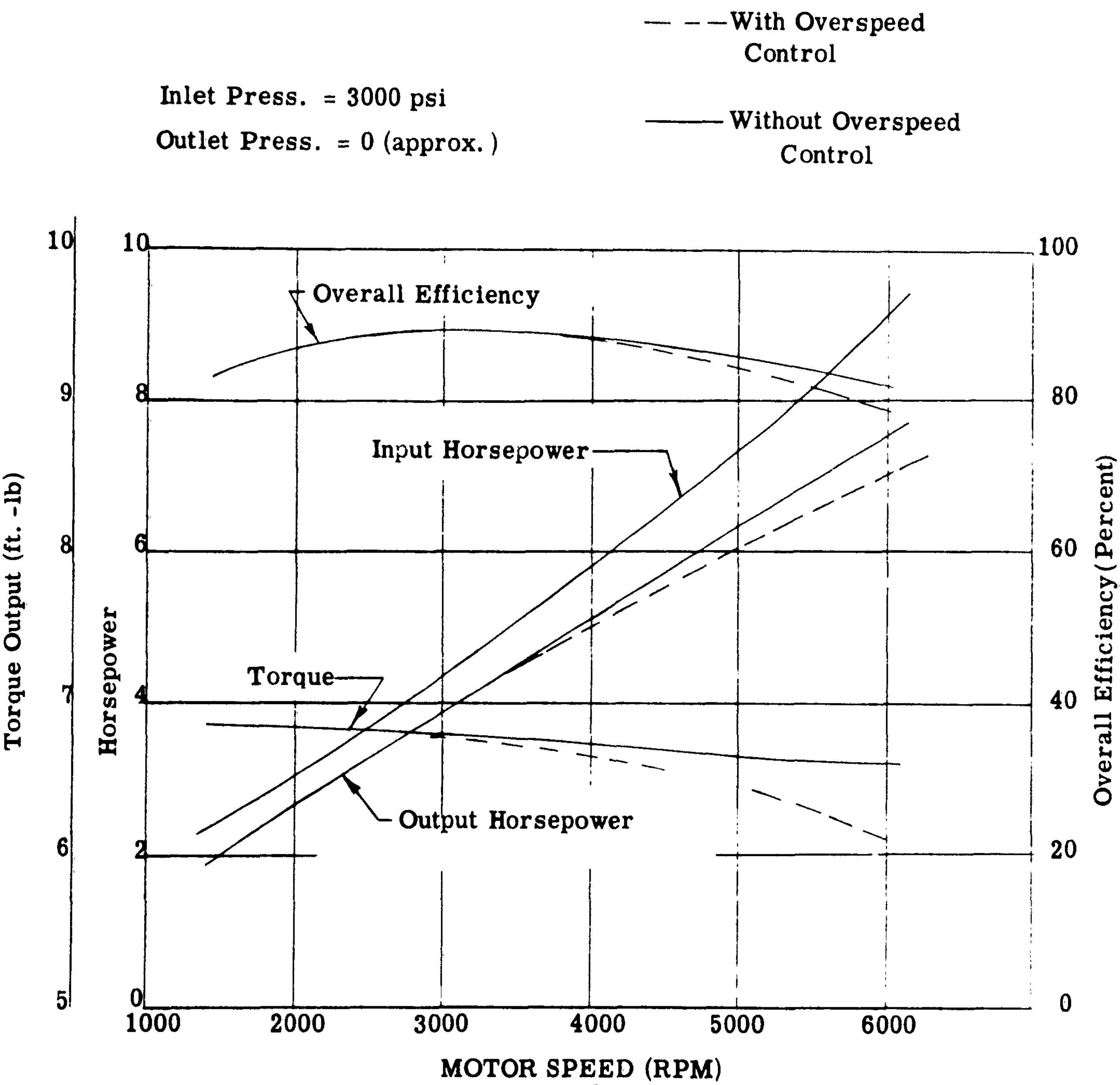


Figure 36

CONTINENTAL MOTORS CORPORATION

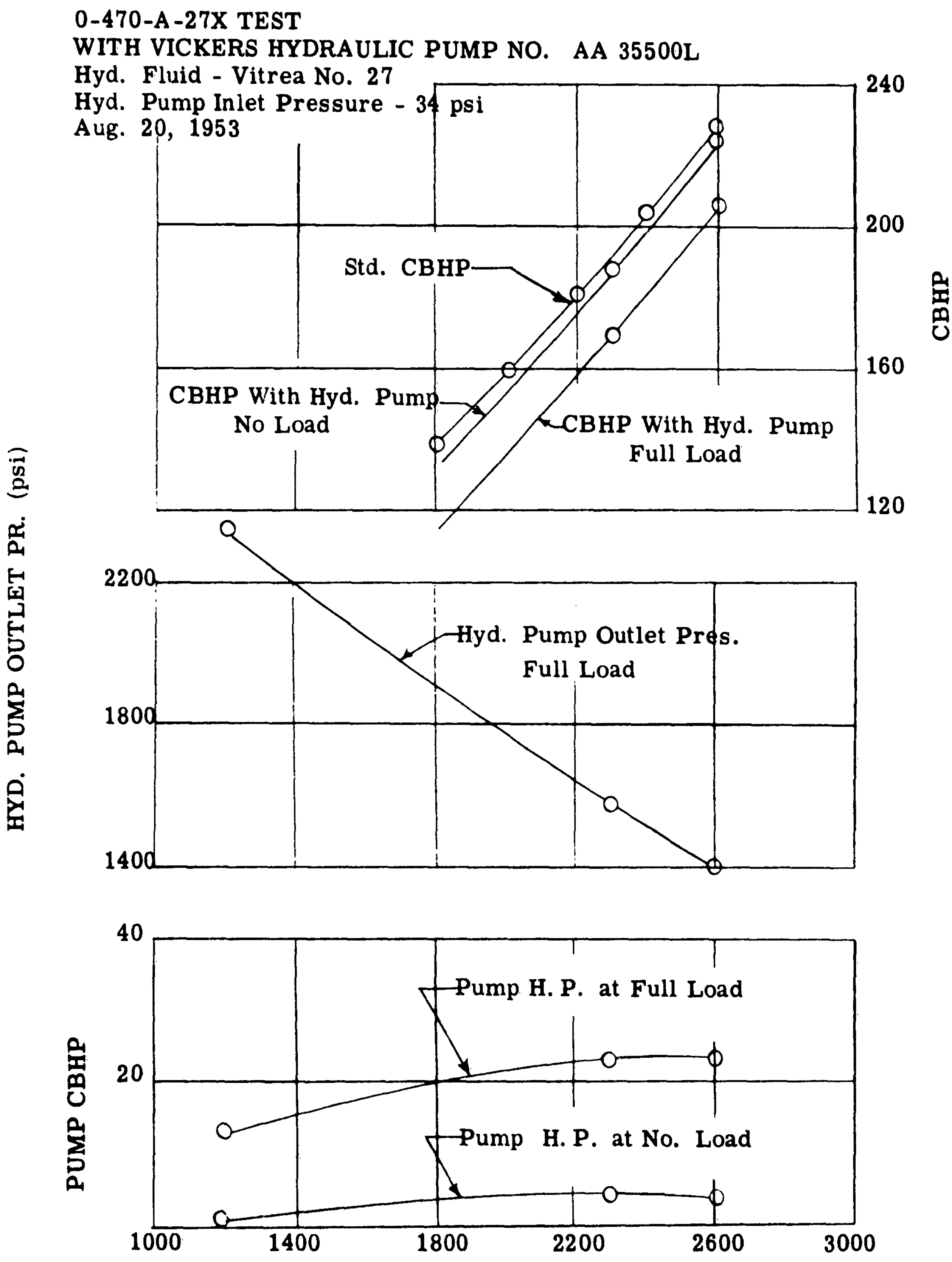


Figure 37

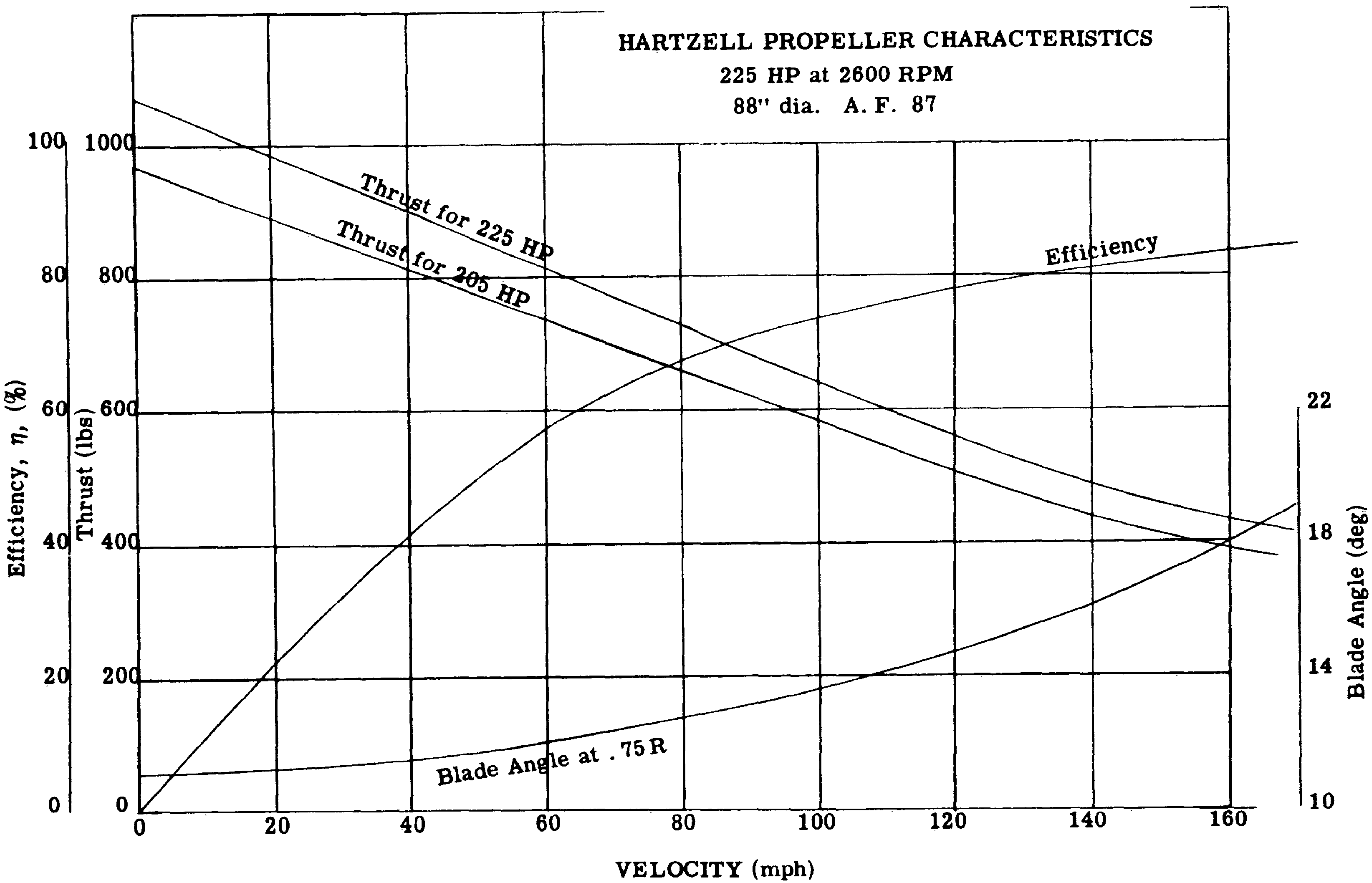

HARTZELL PROPELLER CHARACTERISTICS
225 HP at 2600 RPM
88" dia. A. F. 87
Thrust for 225 HP
Thrust for 205 HP
Efficiency
Blade Angle at .75 R
Efficiency, η, (%)
100
80
60
40
20
0
Thrust (lbs)
1000
800
600
400
200
0
Blade Angle (deg)
22
18
14
10
0
20
40
60
80
100
120
140
160
VELOCITY (mph)

Figure 38

CONSTANT CROSS-SECTION VORTEX DUCT

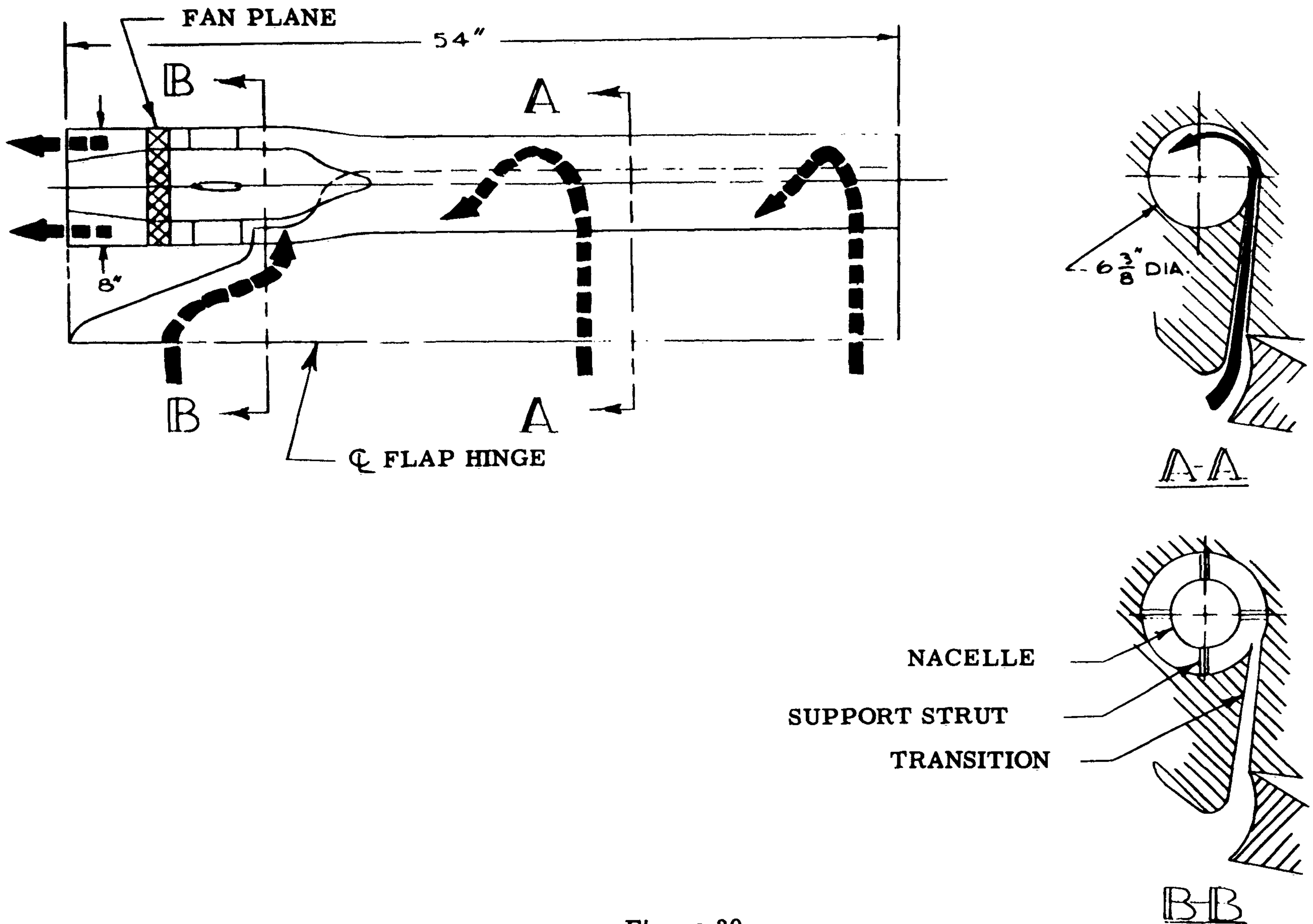


Figure 39

MODEL 319A

CONSTANT LOSS SUCTION DUCT

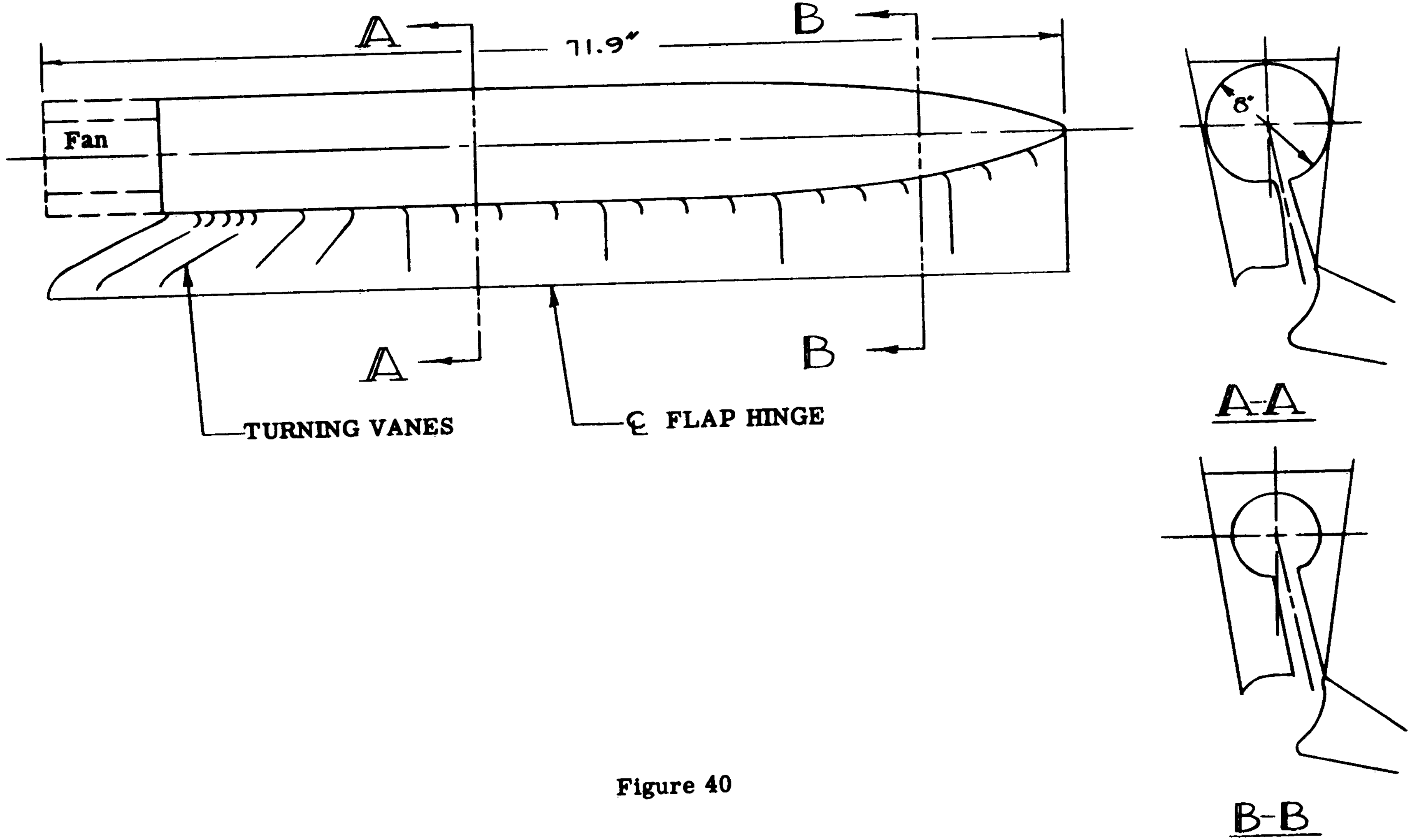


Figure 40

MODEL 319A

BLOWING DUCT AND DIFFUSER

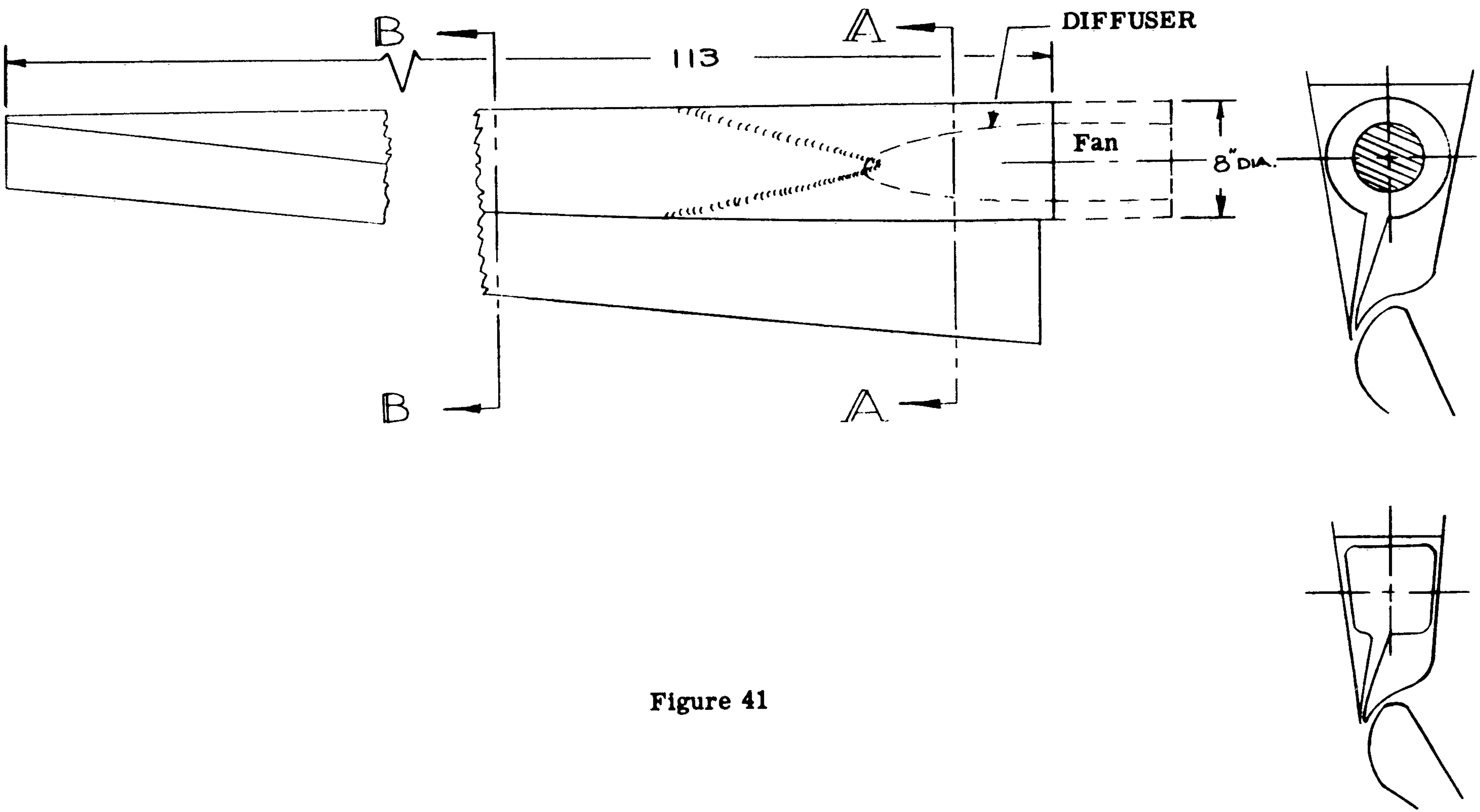
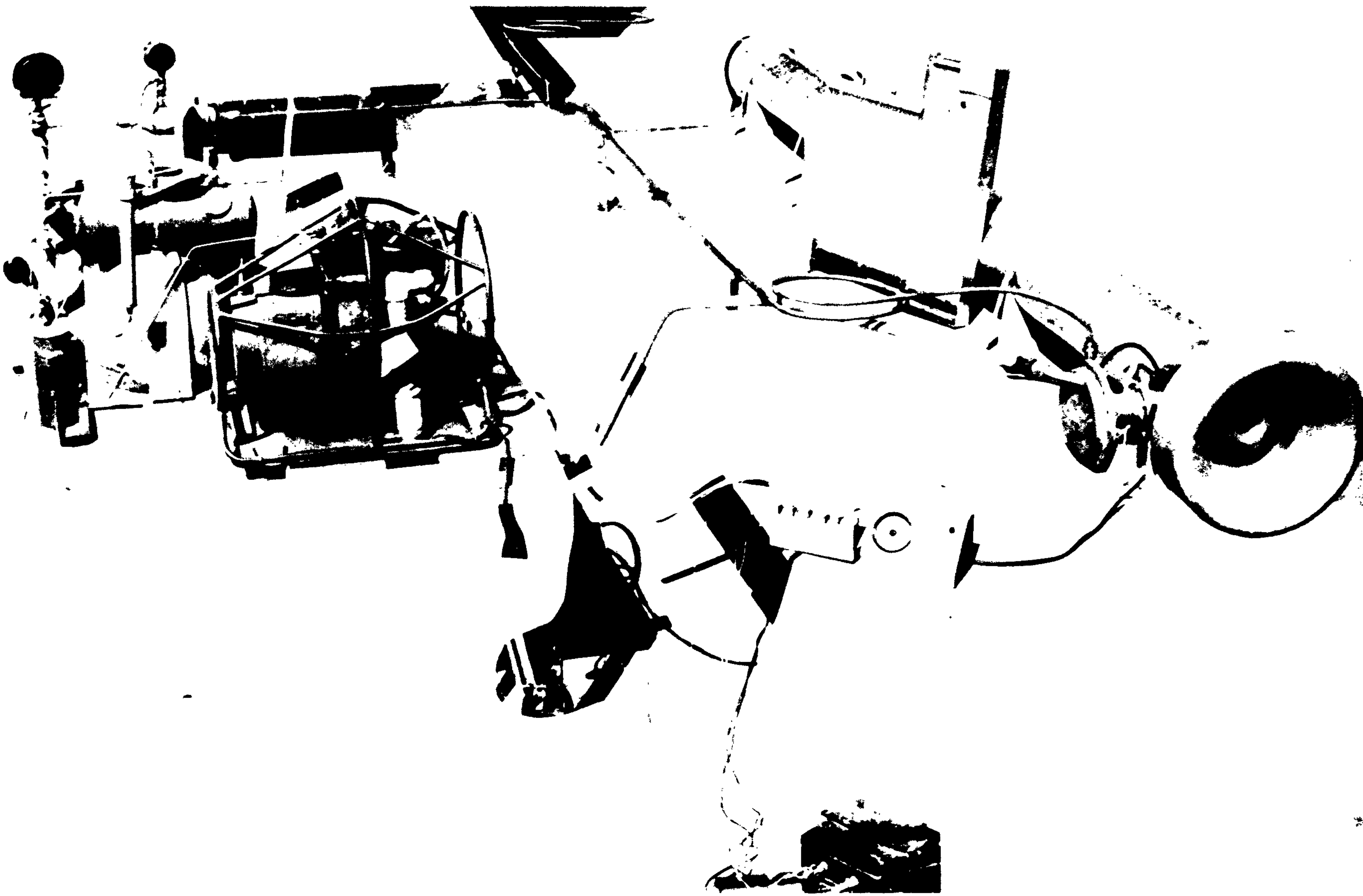
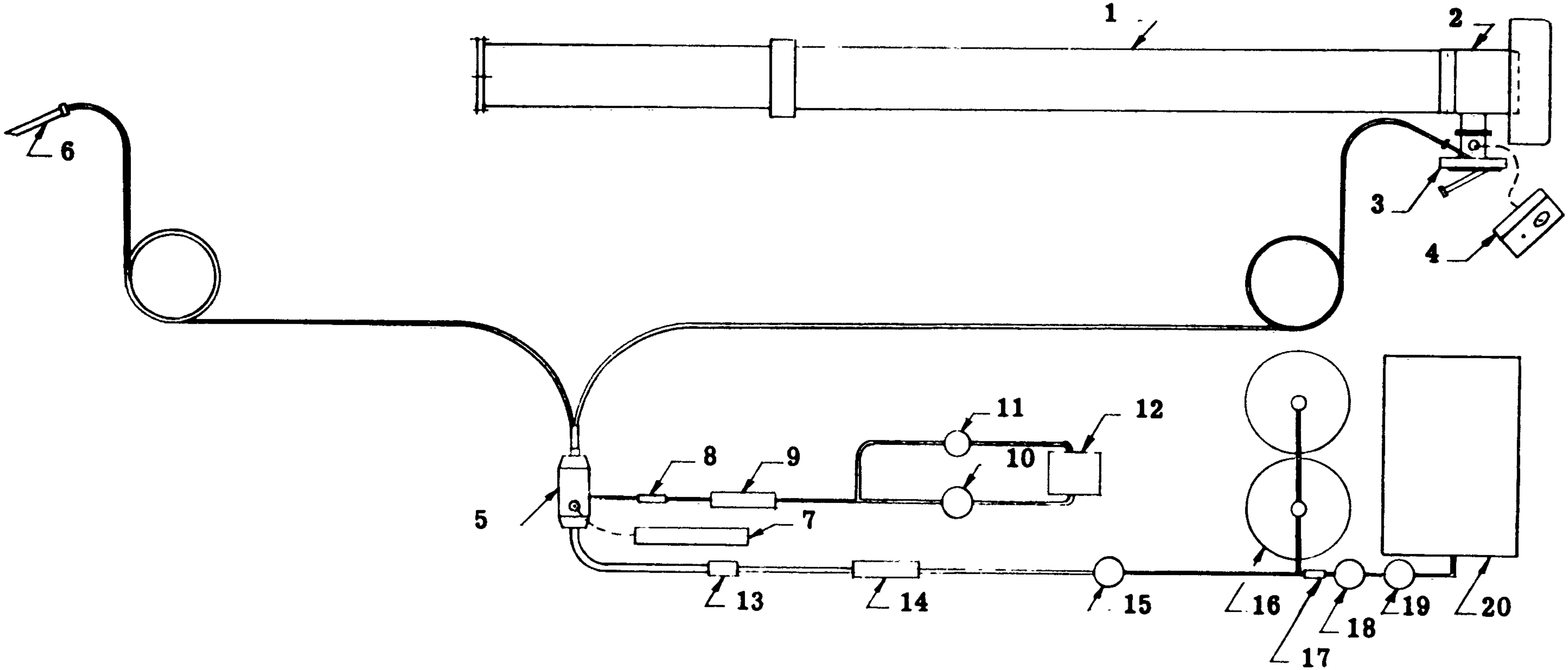


Figure 41



AIR GAS TURBINE BENCH TEST ASSEMBLY

Figure 42



Air Gas Turbine Bench Test Assembly

1. Duct Assembly
2. Fan
3. Turbine
4. RPM Indicator and Overspeed Control
5. Gas Generator
6. Nozzle
7. Igniter
8. Check Valve
9. Fuel Solenoid Valve
10. Fuel Pump
11. Fuel Pressure Regulator
12. Fuel Tank
13. Check Valve
14. Air Solenoid Valve
15. Air Pressure Regulator
16. Air Pressure Spheres
17. Check Valve
18. Chemical Dryer
19. Pneumatic Dryer
20. Compressor

Figure 43